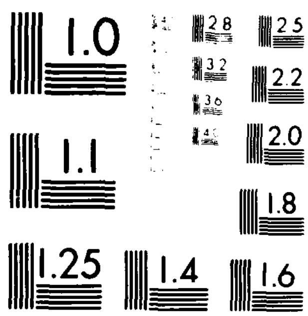
AD-A097 285 NAVAL AIR TEST CENTER PATUXENT RIVER MD F/G 5/8

ADVANCED AIRCREW DISPLAY SYMPOSIUM (3RD), 19-20 MAY.(U)

1976

UNCLASSIFIED NL

1 of 5



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL II

2

THIRD

(6) ADVANCED AIRCREW DISPLAY

SYMPOSIUM (3rd),

19-20 May 1976.

(12) 413

(11)

19 - 20 MAY 1976

81 4 3 12

CONTENTS

THE NAVAL AIR TEST CENTER
THIRD ADVANCED AIRCREW DISPLAY SYMPOSIUM
WEDNESDAY 19 MAY 1976

TIME	EVENT	PARTICIPANT/LOCATION
	REGISTRATION	
0800	Continental Breakfast	
0900	Welcome Aboard	RADM J. H. Foxgrover Commander, Naval Air Test Center
0915	Introductory Remarks Navy Posture	Ms E. Beggs NAVAIR (AIR-360)
0945	Air Force Posture	Brig. Gen. C. H. Cathey Dep. Dir. Development & Acquisition
1015	Coffee Break	
	DISPLAY OPERATIONAL RQUIREMENTS	
1030	CDR Ready, USN	CO VF-24
1050	MAJ Stearns, USAF	F-15 R&D
1110	MAJ Beatty, USAF	F-15 R&D
1130	MAJ McCusker, USAF	Proj. Speckled Trout
LUNCHEON		
	Demonstration/Displays	Officers Club
1300	Guest Speaker	RADM E. R. Seymour Plans & Programs, NAVAIR
	DISPLAY OPERATIONAL REQUIREMENTS (CONT.)	
1400	CAPT Schoeffel, USN	OP-962
1420	CDR Lee, USN	CO-VA-147
1440	CDR Belcher, USN	CO VA-165
1500	LCDR Mitchell, USN	AIRPAC LSO
1515	Break	
1530	F-18 UPDATE	Mr. G. Adam McDonnell Douglas
1600	Maneuvering Flight Path	Mr. F. Watler Northrop
1630	Rational Study of Aircraft Piloting	Col Klopfstein French Air Force
1700	No Host Reception Demonstrations/Displays	Officers Club

THE NAVAL AIR TEST CENTER
THIRD ADVANCED AIRCREW DISPLAY SYMPOSIUM
THURSDAY 20 MAY 1976

TIME	EVENT	PARTICIPANT/LOCATION
0800	Continental Breakfast	
	TECHNOLOGY	
0830	Wide Field of View Diffraction Optics	Mr. R. Lohmann Hughes Aircraft
0900	Holographic Imaging Second Generation	Dr. S. Benton Poloroid Corp.
0930	High Acceleration Cockpit	Mr. P. Kulwicki/Mr. J. Sinnett USAF AMRL /McDonnell Douglas
1000	Coffee Break	
1015	Solid State Helmet Mounted Display	Mr. C. J. S. Lewis E. A. Industrial
1035	Helmet Mounted Energy Management	LCDR Moroney NMC Pt Mugu
1100	Display Techniques for Aerial Gunnery	Mr. C. Ide General Electric
	LUNCHEON	
	Demonstrations/Displays Introduction of Speaker	Officers Club
1300	Guest Speaker	RADM R. C. Mandeville Aviation Plane & Requirements OPNAV
	COLOR FOR FUTURE DISPLAYS	
1400	Evaluating the Characteristics of Luminous Colored Cockpit Displays	Mr. J. Burns Dumont Corp.
1430	Integrated Color Display System	Mr. D. L. Evans Lockheed California
1500	Tactical Air Applications for Advanced Multisensor Imagery Processing and Display Techniques	Mr. T. Stinnett Westinghouse
1530	Break	
1545	Impact of Multicolor Penetration Cathode Ray Tube on Display Cost and Reliability	Mr. F. D. Bloomstran Raytheon
1615	Analysis of Color and its Effectiveness	Dr. R. Christ New Mexico State University
1645	Summary	RADM J. H. Foxgrover Commander, Naval Air Test Center

PROGRAM CHAIRMAN: MR. HOERNER

TECHNICAL ADVISORS:

MR. SELTZ

MR. FIELD

ADMINISTRATOR: MS. ELLEN NELSON

SPONSOR: GEORGE TSAPARAS

200 Years of Evolution

From Minute Man to Multi-Mission

Brigader General Carl H. Cathey, Jr. USAF

Deputy Director Development and Acquisition Systems

DCS/RD

INTRODUCTION

Good morning, ladies, gentlemen, and fellow flyers. That's not to say flyers are not ladies and gentlemen, but to highlight what a pleasure it is to lead the Air Force participation with aviation minded folks in this Symposium which addresses the challenging and critical subject of advanced displays. The Air Force shares your concern over fielding optimum displays which enhance achievement of operational requirements. This symposia demonstrates the fact that we are on the threshold of a display technology revolution which will guide the way to previously unachieveable improvements in mission accomplishment. And equally as important as the technologies, this symposium demonstrates recognition of the need for increased interelations among military aviators of not only the U.S. Army, Navy, Marines, and Air Force but also those of our allies.

Technology and management have yielded considerable progress in the past two hundred years. Our mission is still to fly and fight; but we must do it such that we can counter an increasingly sophisticated and varied threat with a shrinking budget and a dwindling pool of resources. We can no longer afford the luxury of large numbers of aircraft; the few that we do purchase have to do more with a high probability of survival, and be affordable. The demands on the man in the cockpit, therefore, become ever greater and the crew station with its array of information transfer devices then becomes the potential "achilles heel" of an otherwise effective system.

To place the problem in perspective, it seems appropriate to talk briefly about how present-day cockpits evolved before moving on to specific types of problems, constraints, potential future needs, and opportunities.

COCKPIT EVOLUTION

Historically, cockpits have tended to grow in complexity in almost direct proportion to the job the aircraft is designed to do and the systems necessary to allow it to do it.

Display problems in the first cockpit did not exist; there was no place to put a display even if one was available. It was truly a fly by the seat of the pants affair.

The mission of the WWI Spad was rather simple, and its complement of instruments was also austere. History reports some heroic episodes.

The situation became a bit more complicated with the WWII P-51, but was still manageable in what was essentially a VFR fighter whose main task was to fly faster and maneuver better than an equally visually restricted enemy. Again the highly skilled aircrew overcame many machine limitations.

The F-111, represented a virtual quantum leap in mission complexity. The problems and costs associated with trying to fit in all the subsystems required for mission performance were great. The trend shown by this escalation had severe implications to the cockpit display designer.

As you can see, over the years, speed envelopes have increased as mission requirements became more stringent.

Along with that upswing was an attendant increase in the numbers and kinds of systems, which in turn, created a profusion of controls, switches, and displays. The situation bordered on total aircrew saturation.

The problem, of course, as you are aware, takes on even greater proportions in single-place modern fighter aircraft such as the F-15 and F-16. Functional display integration in these two aircraft has taken us a long way, but the heretofore essentially analog technology base constrained development of a full-blown integrated crew station.

PROBLEMS/CONSTRAINTS

The future poses an even more formidable challenge. Extensive mission and threat analyses give us a rather disquieting projection of severe land-based operating environments in several theaters, typified by widely varying weather, as well as Georgraphical and Political constraints.

To counter this threat, we must have increased numbers and kinds of sophisticated systems and subsystems. With the trend toward reduced crew sizes, we no longer can tolerate a dedicated display cockpit. Greater information requirements with the attendant questions of what, how much, and where to put it, call for a flexible display approach.

The pilot cannot be the information integrator; he must be a weapon system manager. This circumstance dictates an overall systems approach to the cockpit. The methodology for this approach is in hand, but to do the job properly, we require increased flexibility both on the front and rear of the panel.

Digital technology is essential to achieving this objective. The systems integration potential of the Digital Avionics Information System (DAIS) concept is, therefore, critical to the development of future aircraft, particularly of the fighter class.

So important is the cockpit to the creation of effective aircraft weapon systems that the Air Force recognized it as a critical element of the development process for the Advanced Tactical Fighter. This sophisticated ground attack weapon system is now in the technology feasibility investigation phase and we see a crucial need for advanced display development to go hand-in-hand with, and perhaps be a driving function in, the rest of the design process. We are being driven in

these new directions by several constraints, some of which I have already mentioned.

Increased mission demands are staggering. We must be able to effectively deal with a potential adversary who may have numerical superiority and whose defenses are both highly sophisticated and strategically massed. We may be operating in a highly weather-restricted environment in a fast-paced conflict whose rapidly changing pace demands near real-time intelligence and ever closer command and control. We must deploy and marshall our land, sea, and air resources quickly and efficiently and support them when we get there. We must, therefore, minimize manpower in order to meet mobilization requirements and insure that our systems have increased reliability. And, to top it all off, we have to factor in cost.

Technology developments in aircraft performance and avionics should allow us to meet these demands in terms of capability, but they complicate the man-machine interface problem.

The requirement for higher combat speed brings with it shorter reaction times and less time per engagement. Displays must, therefore, present only the information needed, when it is needed and in a mode which insures effectiveness.

Increased maneuverability brings higher accelerations and reduced physiological performance on the part of the pilot. He can be protected by supination which allows greater aircrew performance under "G's", but at the penalty of significantly reduced display area.

Fighter aircraft are also being driven down in size which creates an extraordinary real estate problem. Witness F-15 versus F-16 panel as seen here.

Advanced sensors, navigation systems, weapons and delivery systems proliferate, each one with its own control/display needs competing for primary panel space. This situation vividly demonstrates that the limited control and display resources must be shared among several subsystems; while avoiding abiguities and pilot confusion.

Increased thrust-to-weight ratios and advanced flight controls add a new dimension to the demands on the aircrew.

We must, therefore, be far more efficient in dealing with the man-machine interface. The only way to accomplish that goal is to include the pilot factors issues of control/display interaction in the design process from the outset. We must become anticipatory rather than reactionary in cockpit development. We must truly build the cockpit around the man.

WORK TO BE FINISHED

Now that we have reviewed the evolution of the past and defined objectives for the future of crew stations, it is appropriate to discuss some of the practical problems that must be solved before the full benefits from these new concepts can be realized.

From a display component standpoint, there will be an increased reliance on electronic displays and at the same time the cockpit volume and viewable panel space will continue to shrink. This will make display volume and form factors more important than before. In addition to this, it is important to note that the cockpit will increasingly be dependent upon electronic displays for the presentation of critical flight and weapon control information. Of course catastrophic failures in these applications are of major concern. Consequently, the Air Force is exploring the potential benefits to be gained from the new display technologies which are emerging, such as liquid crystal and LED matrix displays. We have sponsored developmentof circuitry for driving liquid crystals such as the matrix array shown here. This array consists of 10,000 picture element drive circuits fabricated on a one inch square silicon substrate. Similarly the LED matrix display under development by the Air Force is composed again of 1 x 1 inch replaceable display modules, each with a resolution of 64 dots per inch. It appears that these techniques will not beat the basic CRT display on a cost basis alone in the immediate future.

However, cost of ownership analysis indicates that it is easily justifiable to pay considerably more for a display initially if it provides higher reliability and simpler maintenance in the long run. Of course it is going to take time and large capital investments (probably by private industries in many cases) to bring these technologies to the production line. So that in the immediate future designers must continue to live with the constraints imposed by the components that are available today.

On the other hand, suppose that the flat plate solid state display was here today and computers had been pursed by competition further down the cost curve and a software cost breakthrough occurs. Is the job over? Are we there? Fortunately for those of you employed in this industry, the job has only begun. These technology developments will open the door to many new possibilities in crew station design.

The optimum crew station configuration for a specific application is located somewhere in the multi-dimensional space depicted in this vugraph. The problem is to make the appropriate tradeoffs necessary to locate the design properly for best crew performance. This is obviously a difficult task involving many subtle factors.

For instance, consider the following items as typical examples of the design questions that need to be answered:

Now that the cockpit can be, subject to a few limitations, reprogrammed in flight to a multitude of configurations, the crew station system designer has a list of options that boggle the mind. How many should be used and how should failure or backup modes be accommodated? Obviously these questions will yield to common sense and experience, eventually, but at the moment this is almost virgin territory.

Then consider the problems relating to data flow between man and this highly specialized computer complex that has replaced the fixed "dumb" response of traditional cockpits. There is a tendency to think in terms of exchanging information in a manner similar to that of a computer terminal where the man is dedicated and the machine is time-shared. Ways must be found to free the crew from the burden of extensive keyboard operations and turn the relationship around -- dedicated machine, time-shared man. When the pilot pushes a button - an immediate feedback should confirm systems are ready and desired actions will follow when commanded.

The introduction of computer-driven displays opens up the opportunity to employ many forms of graphic displays which were not feasible before. This is a new art form for the cockpit designer and much remains to be done to establish the practical limitations of graphics and most appropriate applications of this technique.

Finally, there is the question of display metrics for matrix displays. The science of display metrics is still evolving and the quality of CRT displays is not yet totally understood. The matrix display with its two-dimensional raster is a different device and there are now new questions to answer concerning the unique attributes of these displays.

We are not at the cross roads where the man, with his tremendous innovative and adaptive capabilities, may be the limiting factor in mission performance. The man is more talented and versatile than any computer and we must turn our technologies to take advantage of this fact. Moreover, the computer has capabilities often limited only by our programming smarts.

So you see from this partial listing there are many problems remaining to be solved, and I am sure that many of you in the audience are thinking right now about items that should be added to this list.

TOTAL INTEGRATION

There is one remaining problem to be solved if the crewman is to become a "total system manager" and that is the integration of all the pertinent avionic information into a system that can exchange and process

data on a higher level of sophistication than has ever been done before. For example, there may be many sources of navigational information on an aircraft. It is perfectly logical to integrate this and select the most accurate source or form a weighted average. Then this single source could be distributed as required. But what is thepilot's role in this as a manager. Should a fault detection automatically cause one nav. - source to be substituted for another, without pilot intervention, and suppose the TACAN unit is really displaying information from a GPS source. What is the effect on crew confidence? This is a simple example of the sorts of things that need exploration.

Because of the complexity of these data systems, it will require a system test bed for development where concepts can be implemented and refined on an iterative basis, something like this vugraph depicts. This is going to require a system simulator of extreme flexibility which has the capacity to exchange data with a myriad of points scattered throughout the total avionics system and the ability to process and redistribute this data in accordance with programmable instructions. Fortunately, Air Force has such a test bed under development as part of the DAIS Advanced Development Program at Wright Patterson AFB.

The original objectives of DAIS included the development of a digital avionics architecture that could provide a significant improvement in display hardware in terms of reliability, maintainability, flexibility, and lower life cycle costs.

Now that the DAIS architecture has been defined and hardware and related software are being assembled, attention can be turned to evaluation of specific system concepts and configurations. Plans are being formulated to do extensive evaluations of total systems, and theplans for crew station evaluations include both fixed and moving base test conditions.

In summary, let it be said that the DAIS test bed offers a unique capability to evaluate and refine total system designs, and it will be fully exploited in the future to develop better crew station systems for the Air Force and our friends.

FINAL

We in the R&D community must insure that those of us who are sent to fly (both United States and allied aviators) are capable of fighting at peak efficiency. Our mission is to fly and fight worldwide under any conditions and win.

We must ensure that our aviators gain the combat edge.

Gen Doug MacArthur summed i up with the bottom line.

Thank you for this opportunity to participate in your symposium and keep pressing on!

INTRODUCTION

Some elements which must be considered during display design:

(1). Advancing technology of computers and displays is yielding the capability to begin with the forward portion of the cockpit a blank drawing board and to present specifically what the pilot needs to accomplish the specific mission segment - normal or combat.

(2). Along with this capability goes almost total design flexibility, which is essential as it is virtually impossible to anticipate the uses and requirements of a future era. Consider - the possibility exists (if for no other than fiscal reasons) that a weapon system conceived today, introduced 5 to 10 years hence; will remain in the active inventory for some twenty years after introduction. We are talking a time interval of nearly 30 years from conception. However, as desireable as flexibility is, it is extremely expensive (software costs becoming greater than hardware) so that thorough pre-planning of the display content and format is necessary to minimize future changes.

(3). Changes in the National Airspace System - MLS for instance: Methods of guidance must be devised for flying curvelenear approaches/ departures and integrating time into the display.

(4). The capacity for truly all-weather (at least low visibility) is within the reach and is particularly critical for the military role.

To achieve this goal, not only must displays of position, projected position, and time be devised; but we must extend our sensory abilities to present literal real world imagery. We need the technology to produce this and overcome problems of current IR or KU, KA band radar. Possibly something of a multi-spectrol approach. Intuitively, it may be more desireable to develop an on instrument to touch down capability rather than attempt to enhance the transition from instrument to visual. Actually Cat II conditions may be more hazardous than properly instrumented Cat III.

Back to the subject of information requirements, more specifically, as it is very easy to spell over into displays, I have broken these into requirements for various mission segments.

INTRODUCTION

1. ME
2. EXPERIENCE - Limited
   a. TRAINER - INSTRUCTOR (T-37, T-38, T-39)
   b. FIGHTER - F-100
   c. RESEARCH - IFC (T-38, T-39, T-29)
   d. TRANSPORT - T-39
3. INTRODUCTION
4. BROKEN DOWN MISSION SEGMENTS
   a. BASIC-UBIQUITOUS TO ALL PHASES
   b. TAKE OFF
   c. CLIMB-CRUISE-DESCENT
   d. APPROACH-LANDING

BASIC - UBIQUITOUS

1. ANNUNCIATION

   a. RADIO IN USE

   b. RADIO PRE-SET

   c. BOTH COMM & NAV

   d. FLIGHT DIRECTOR MODE

   e. AUTOPILOT-INDENTURE

   f. FAILURE WARN.

2. NAV. POSITION

   a. WAYPOINT-FIX IN USE

   b. DISTANCE TO SELECTED WAYPOINT/FIX

   c. <u>TIME</u> TO SELECTED WAYPOINT/FIX

   d. STEERING-RAW & COMMAND

3. ALTITUDE

   a. CALIBRATED - ALL THE TIME

   b. ABSOLUTE AT LEAST BELOW SOME PRESELECTED LEVEL (2500'-3000' ETC.) MIGHT VARY DEPENDING UPON MISSION FIGHTER,TRANSPORT, ETC.

4. SPEED

   a. CALIBRATED A/S

   b. TAS (available)

   c. G.S. (available)

5. PITCH AUGMENTED RATE (IVSI), NOT NECESSARY IF FPA USED.

TAKEOFF

1. ENGINE PERFORMANCE

    a. LIMITS

    b. POWER OUTPUT

    c. FAILURE WARNING VS. RAW INSTRUMENTS

2. ACCELERATION

    a. TIME

    b. SPEED VS. DISTANCE (RUNWAY MARKERS OR DME)

    c. LONGITUDINAL ACCELERATION

    d. ENERGY MANAGEMENT

3. SPEED

    a. ROTATION

    b. REFUSAL

    c. ETC.

4. ABORT COMMAND

    a. FAILURE WARNING & ANNUNCIATION

    b. DEGRADATION LEVEL

    c. ABORT DECISION-COMMAND

5. BASIC REQS.

    a. ATTITUDE

    b. HEADING

    c. RUNWAY ALIGNMENT-DEVIATION FROM A COMMAND INFORMATION (STEERING AND ROTATION)

CLIMB-CRUISE-DESCENT

1. BASIC INFORMATION

   a. NAVIGATION GUIDANCE

   b. DRIFT ANGLE

   c. WIND VELOCITY

   d. ENGINE MONITORING-FAILURE-WARNING-IMPENDING-ACTUAL

2. CONTROL/PERFORMANCE INFORMATION

   a. ATTITUDE-MUST HAVE PURE ROLL
      -PITCH OK (FPA BETTER)

   b. FUEL-QUANTITY, TIME REMAINING

   c. ANGLE OF ATTACK

      (1) CLIMB-BEST ANGLE/EFFICIENCY (F-111 D)

      (2) CRUISE-EFFICIENCY/MAX RANGE/OPER. RANGE/LOITER

      (3) MANEUVERING POTENTIAL

      (4) MUST BE MEANINGFUL - % OF LIFT AVAILABLE (NORMAL)

3. VERTICLE GUIDANCE (RAW & COMMAND)

   a. CLIMB PERFORMANCE- RATE, FPA, EMERGENCY PERF.

   b. CLIMB POTENTIAL-ENERGY MANAGEMENT

   c. LEVEL FLIGHT

   d. DESCENT - MAX. RANGE
      - SELECTED RANGE
      - TO A FIX

APPROACH-LANDING

1. GENERAL INFORMATION

   a. CALIBRATED AIRSPEED

   b. CALIBRATED PRESSURE ALTITUDE

   c. ABSOLUTE ALTITUDE

   d. TIME - TO SELECTED FIX
   - TO LANDING

   e. ANGLE OF ATTACK - TOTAL
   - EXPANDED FOR FINAL APPROACHED

   f. LANDING SEQUENCE ANNUNCIATION

USAF IPIS (IFC) CONDUCTED EXTENSIVE STUDIES UNDER REAL WORLD CONDITIONS DURING PILOT FACTORS PORTION OF THE SST PROGRAM. I DREW HEAVILY UPON THESE AND UPON MY EXPERIENCE DURING LOW VISIBILITY LANDING STUDIES FOR THE LANDING AREA.

2. TWO GENERAL CATEGORIES

   a. VERTICAL PATN GUIDANCE

   b. LATERAL PATH GUIDANCE - MOST DIFFICULT DUE TO DYNAMICS OF SITUATION, I.E.. DEVIATION NOTED, BANK INPUT, HEADING CHANGE, CORRECTION INITIATED.

3. VERTICLE PATH GUIDANCE

   a. GLIDE SLOPE INFORMATION AND ERROR

   b. PITCH ATTITUDE

   c. PITCH AUGMENTED RATE (IVSI)

   d. FLIGHT PATH ANGLE (NEGATES b & c)

   e. ABSOLUTE ALTITUDE AND RATE (QUALITATIVE)

f. PROJECTED TOUCHDOWN PT.

g. COMMAND STEERING & INCLUDING FLARE

4. LATERAL GUIDANCE

a. CENTERLINE ERROR(LINEAR TERMS VS ANGULAR)

b. LATERAL RATE

c. MAXIMUM TOLERABLE DISPLACEMENT & RATE (TAYLORED ILS)

d. COMMAND STEERING TO - AIRBORNE
- ROLL OUT

5. FOR LOW VISIBILITY LANDING

a. ROLL OUT DISTANCE REMAINING

b. ILM

(1) FPA

(2) AOA

(3) ABSOLUTE ALTITUDE

(4) SYMBOLOGY MUST BE INSTINCTIVE - NO TIME FOR INTERPRETATION

(5) RUNWAY ENVIRONMENT

(6) PROJECTED TOUCHDOWN POINT

PITCH IN FOR MOTHER <u>HUD</u>!

OPERATIONAL REQUIREMENTS FOR ADVANCED FIGHTER AIRCREW DISPLAYS

CDR JOHN K. READY, USN

INTRODUCTION

I appreciate the opportunity to participate in this Advanced Aircrew Display Symposium and, as a fleet representative of Navy fighter aviation, I fully endorse the purpose and objectives of this meeting. When I was assigned the task of addressing such a distinguished group I felt uncomfortable because, first, I've had very limited experience with advanced cockpit displays, and secondly, fighter pilots are notorious for being dumb and ornery. As a matter of fact, just the other day I read an inscription hanging on the wall of a noted fighter pilot which read "A MIG AT SIX O'CLOCK IS BETTER THAN NO MIG AT ALL."

Well, I hope to overcome that image and give you insight into how a fighter pilot thinks in the air and what type information he needs. Perhaps I can relay some ideas on improving and simplifying his management of cockpit data.

I feel that our ultimate goal in the fighter decision tree is what you see on this slide. The basic tactics of air combat are unchanged; the aircrew must still analyze their own skills, aircraft, and weapons, and weight them against those of their adversary in order to fight and win by shoving it up his tailpipe. Technological advances and new weapons systems have extended the nature of air combat and have placed greater demands on the skills of the aircrew. The complexity of the fighter role is ever increasing. Here are our problems:

(1) The logic in achieving a weapons solutions is elaborately interrelated and interconnected.

(2) Total information on aircraft performance, weapons systems, threat capabilities and tactical situation is needed.

(3) The numerically inferior scenario is real, and

(4) We will always have the restraints of positive identification.

These are real world problems and is the basic philosophy of our training. I've seen accidents, increased training requirements and mission ineffectiveness from the aircrew's inability to assimilate, evaluate, react to, and judge cockpit information in this most dynamic environment. Even many fights are lost because of aircrew preoccupation, misinterpretation, misregistered information, mismanaged weapons systems, and in clear-air-mass, they never saw the enemy.

FIGHTER PILOT'S TASK

Once on an attack vector or in a close-in engagement, the fighter pilot is in an absolute dynamic environment, often with reduced vision and I.Q., and the three basic questions he must satisfy are:

(1) Am I in a weapons envelope with some predetermined probability of kill?

(2) If not, what is lacking: range, relative speed, aiming, or relative angle?

(3) Do I have the combat fuel package to engage, maneuver and escape?

DISPLAY LOGIC

In order to best present the type of information Navy fighter pilots need, I've taken the approach of integrating a multimode weapons system that provides instructions necessary to detect, track, and attack a selected target in a fleet air defense role and/or a "clear-air-mass" air combat role. I've purposely limited my remarks to the basic fighter mission without addressing electronic countermeasure displays, long range identification displays or special fighter tasks.

Again, returning to basics, for both phases of the fighter mission, the philosophy of "see," "decide," "attack," "kill" and "escape" still apply. The fleet air defense phase will always be interrelated and interconnected with the close-in air combat phase. In a long range or short range attack, the pilot must first detect the threats, second analyze the tactical situation, third determine the treat formation, and fourth decide and conduct an optimum flight path. To do this, he must consider:

(1) The method of engaging from a position of advantage.

(2) The best energy level.

(3) The best intercept geometry.

(4) The best weapon.

(5) His fuel consumption, and

(6) The threat capabilities

An advanced display system must provide the pilot with simple, accurate and reliable information to rapidly answer the following questions:

(1) Are my weapons ready to shoot?

(2) Is my energy level adequate relative to the threat?

(3) Is this attack profile optimum?

(4) What is the best weapon to fire?

(5) What is happening around me?

(6) Am I in a valid weapons envelope, if not, what is lacking?

(7) What is the best reattack profile?

(8) Which direction, what fuel state, and at what energy profile should I disengage?

Obviously, all these questions cannot be answered for the aircrew. The aircrew, however, must have the basic, essential information to answer these questions quickly and accurately. I feel that an advanced display system should reduce the transformations that the pilot must make in answering these questions and in successfully accomplishing the basic required fighter tasks. The data displays should change in response to the aircrews actions and the changes in the operational environment, and they must be adaptable to varying tactical requirements as a mission progresses. As an example, I often wonder, for a multiple weapons mix, should I have exclusive control over deciding on weapons selection or should "best" weapon be selected automatically as I progress through the various phases previously mentioned. I wonder what impact this would have in reducing a pilots mental and physical workload.

DATA DISPLAY GROUP

This next slide illustrates a practical approach to the integration of needed information progressing from a surveillance task to a launch or "shoot" task for both the fleet air defense or visual air combat roles. I envision this data display logic to progress from the "heads-down" Tactical Display up to the final goal of "heads-up" Launch Phase for all weapons.

The horizontal display information required consists of:

(1) Target classification:

Surveillance Data
Friendly
Hostile
Unknown

(2) Target Parameters:

Speed
Range (relative)
Elevation (altitude)
Bearing (relative)

(3) Long Range Launch Zones

(4) Reference Points

This must be a 360 degree view of the surrounding tactical situation.

During the "attack" phase, a vertical display is required and the type information required is:

(1) Attitude Reference

Pitch
Roll
Heading

(2) Relative Energy Level

Speed
Altitude

(3) Steering Guidance/Steering Error

Azimuth
Elevation

(4) Target Parameters

Range (Relative)
Altitude
Heading
Speed

(5) Maximum Launch Range

(6) Minimum Launch Range

(7) Weapon Status

During the "launch" phase, the "heads-up" display is a must. In discussing a "heads-up" display, the majority of fleet pilots I've interviewed feel that the concept of a "heads-up" display is invaluable; however, it should

(1) Be uncluttered

(2) Be an aid to line-of-sight to the target

(3) Be used for aiming, and

(4) Except for weapons mode or status, it should indicate launch envelopes by positional indications rather than digital readouts or scales.

Digital readouts and scales have to be "read,", whereas positional displays relay peripherial information. Information needed:

(1) Armament datum

(2) "Line-of-sight" to target (to angle track limits of radar)

(3) Steering guidance

(4) Max/Min Range

(5) Real time gun sight

(6) Weapons Status

So far, I've addressed the basic and essential types of information needed to successfully conduct a fighter mission. As mentioned earlier, this has been a simple approach, addressing only essential information which is frequently transformed by the pilot. Other essential information which is less frequently used, but which should have dedicated indicators or displays are: speed, altitude, ehading and fuel state. The airspeed and altitude requirement is obvious and provides energy management information. I am opposed to an "energy management" or "specific excess thrust" display since energy state is best determined through psychometrics, given good flying qualities and performance, and training. Energy management is a very important concept which every fighter pilot must understand and use; however, in a true "heads-up" fighter these parameters should be "second nature," and, in numerous situations, good fighter pilots may mismanage energy purposely to achieve an advantage or a "kill."

An accurate, simple, and dedicated display of fuel state is essential. It should be easy to read, positional, as well as digital, readout and near the periphery of a "heads-up" scan. Fleet pilots tend to mistrust and misuse associated warning lite or annunciator systems associated with "bugout" or "bingo" fuel. The combat fuel package is influenced by many factors and should be considered in mission planning. An additional aural or warning light system would have limited use and should not replace a simple, accurate, dedicated fuel gage.

A dedicated angle-of-attack presentation was historically used in maneuvering fighter aircraft. These aircraft did not have discernable feel at best instantaneous and sustained flight conditions. If a fighter aircraft is well designed, the pilot can best determine maxim. urn performance by airspeed

information and flying qualities. The most frequent use of angle-of-attack information occurs doing uncontrolled flight and not considered too useful otherwise in air combat.

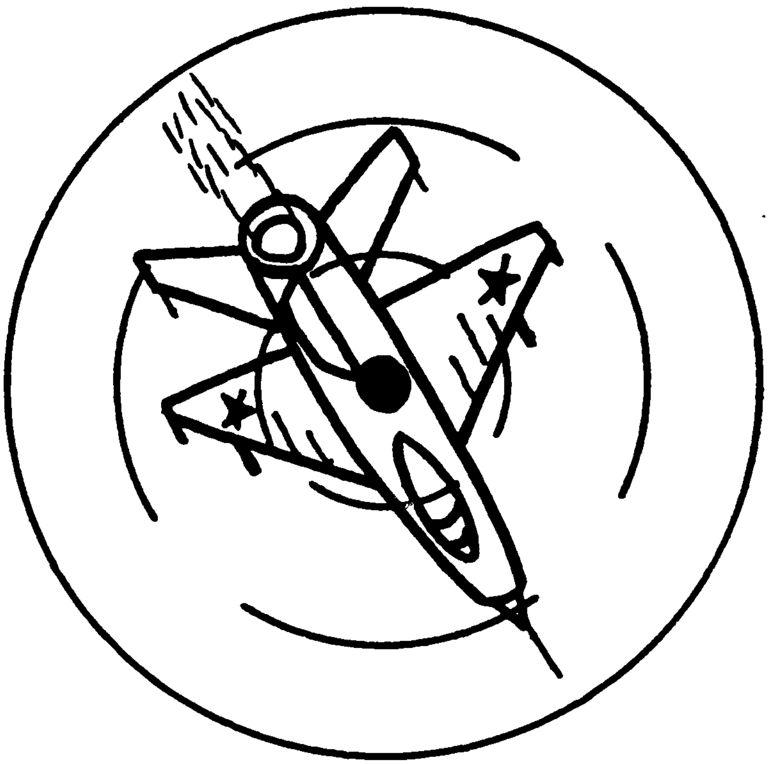
Normal load factor is essential information which does not necessarily require a dedicated display. Most pilots use a G-meter to initiate a maneuver or to determine the degree of overstress after a maneuver. Again, if given good flying qualities and proper training, A G-meter becomes an infrequently used bit of information. Perhaps a warning system of impending limit load factor would be sufficient or a parameter limiting flight control system.

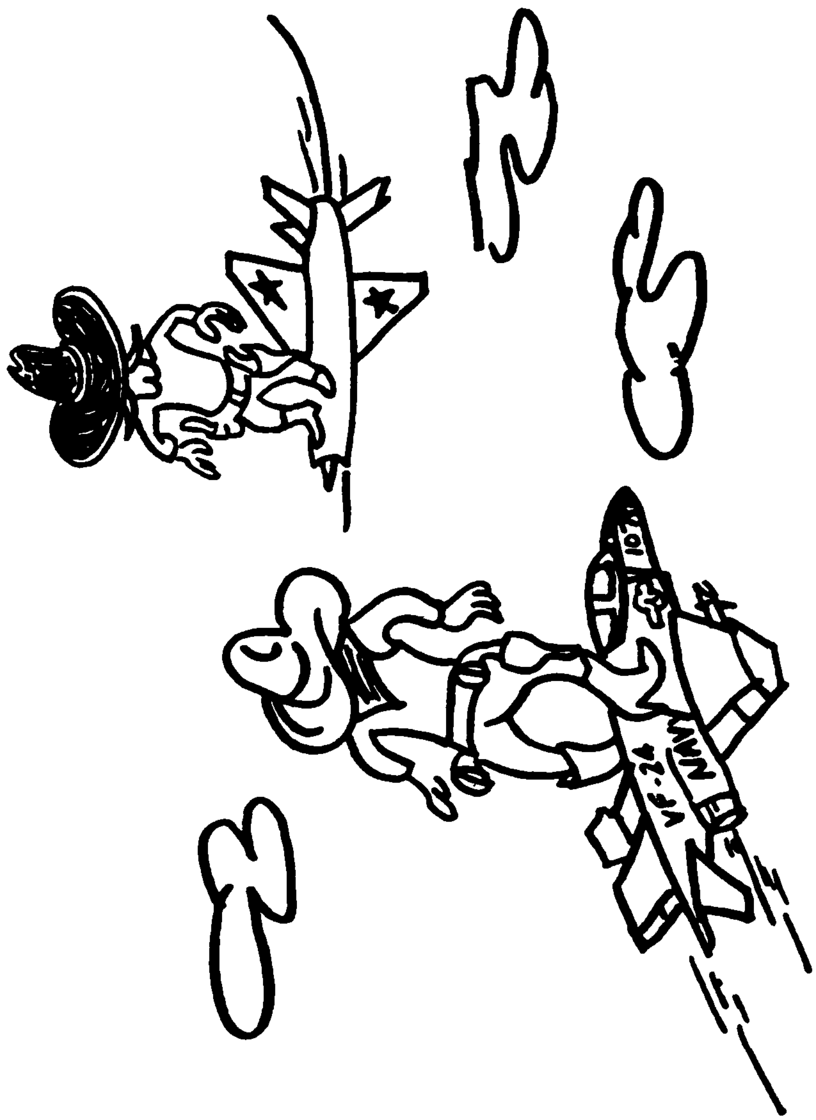
SUMMARY

In summary, all other types of cockpit data are considered to be used infrequently and could best be presented as a situation occurs or as aircrew "call-up" items. This would include subsystem parameters, degradated subsystems, communication, navigation, long range identification systems and emergencies.

I hope that this overview of Navy fighter requirements has been informative. Todays fighter aircrew is in a quandry of limited training, while facing an even more complex fighter mission in the next decade. The demands of weapon management are ever increasing display systems appear to be easier to read, but the volume of information available requires intensive training to manage properly. I firmly believe that we must keep display systems simple, reliable, and accurate. Only in this way, can we "give the average guy a better than average chance of winning." Thank you!

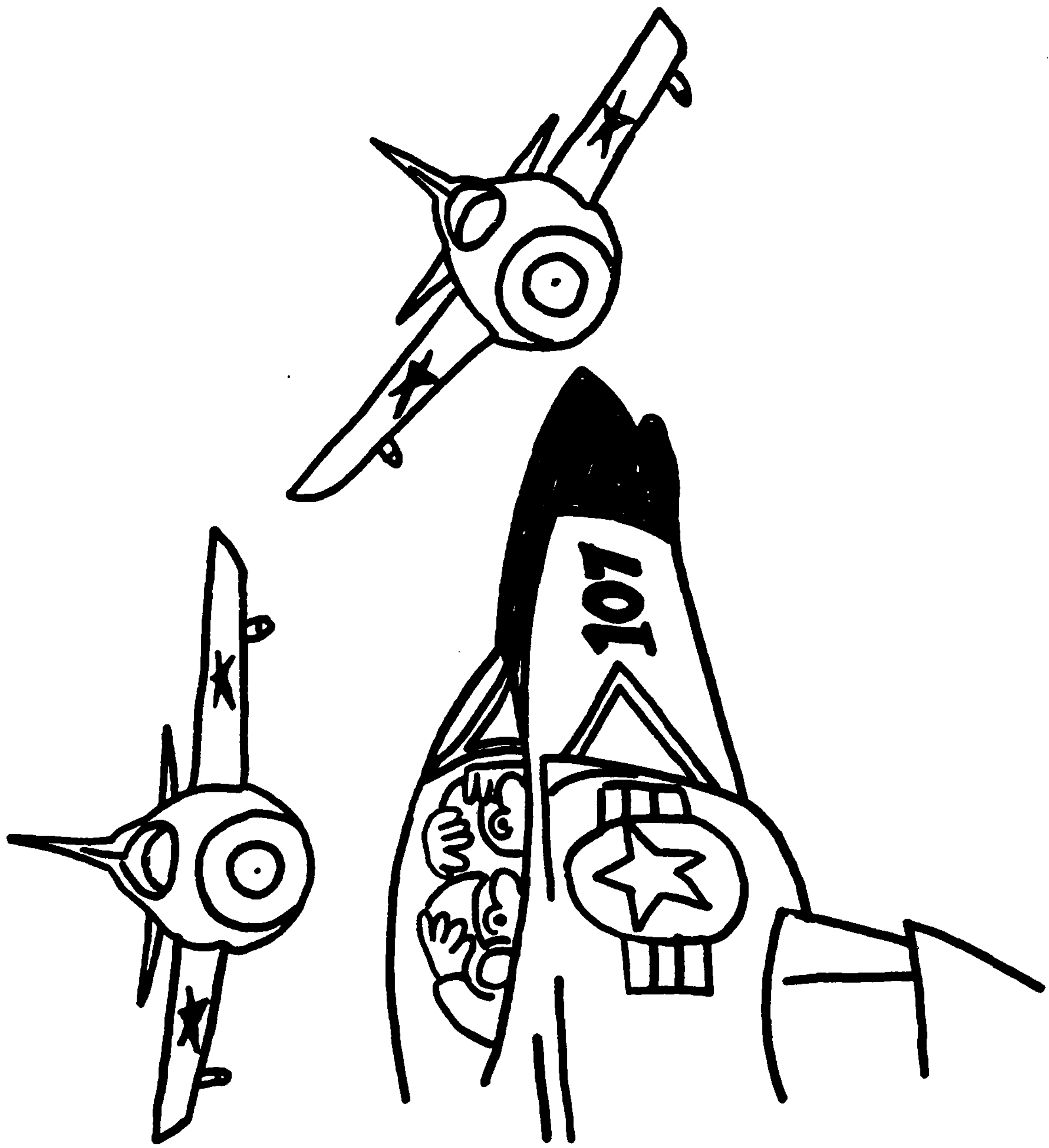
OPERATIONAL REQUIREMENTS FOR ADVANCED FIGHTER AIRCREW DISPLAYS




VF-24
NAVY

MODERN AIR WARFARE

- ELABORATE WEAPONS SOLUTIONS
- NEED FOR TOTAL INFORMATION
- NUMERICAL INFERIORITY
- RESTRAINT OF POSITIVE IDENTIFICATION


107


NAVY

BASIC QUESTIONS

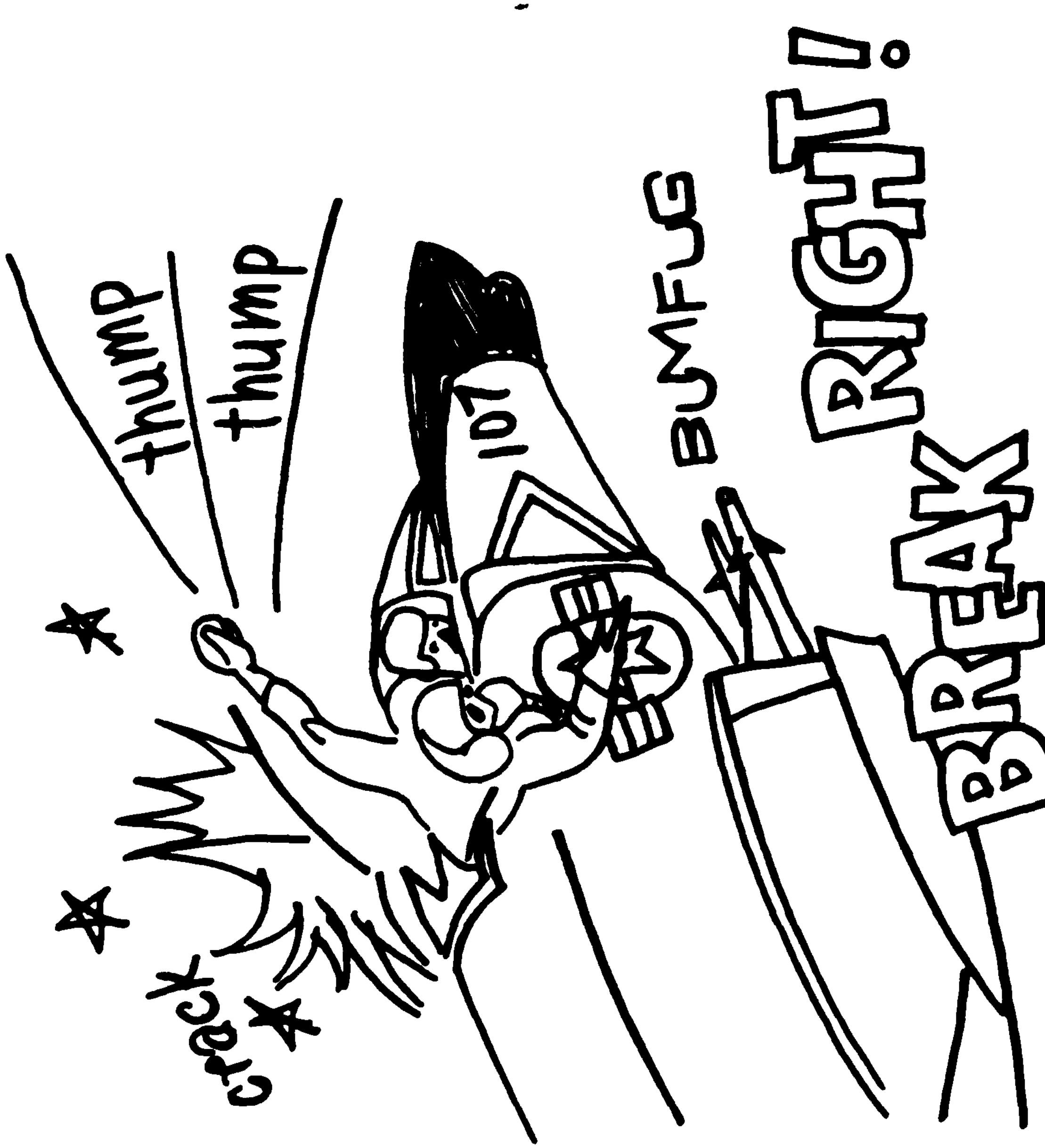
- WEAPONS SOLUTIONS ?
- MANEUVERS REQUIRED ?
- COMBAT FUEL PACKAGE ?

BASIC PHILOSOPHY

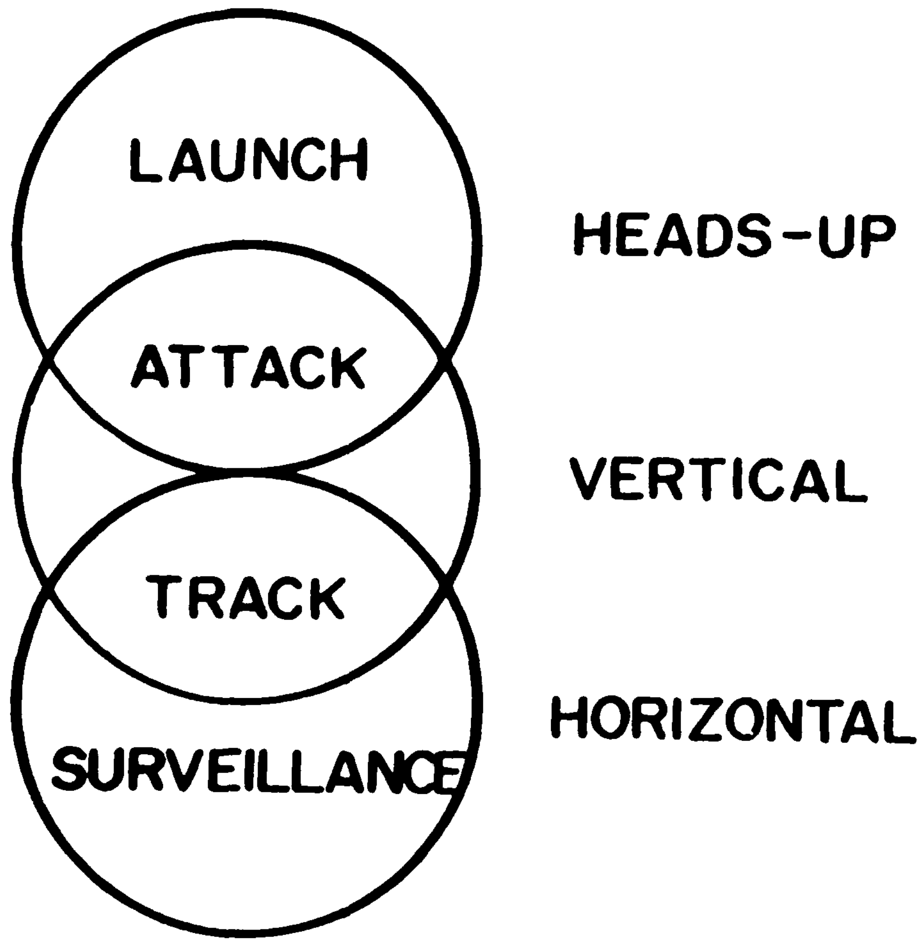
- SEE
- DECIDE
- ATTACK
- KILL
- ESCAPE

CONSIDERATIONS

- ENGAGE FROM A POSITION OF ADVANTAGE
  - BEST ENERGY LEVEL
  - BEST WEAPON
  - BEST INTERCEPT GEOMETRY
  - FUEL AVAILABLE
  - THREAT CAPABILITIES


thump
thump
crack
BUMFUG
BREAK RIGHT!

DISPLAY LOGIC



SURVEILLANCE DATA

- TARGET CLASSIFICATION
- TARGET PARAMETERS
- LAUNCH ZONES (LONG RANGE)
- REFERENCE POINTS

ATTACK DATA

- OWN ACFT REFERENCE
  PITCH / ROLL / HEADING
- RELATIVE ENERGY LEVEL
- STEERING / STEERING ERROR
- TARGET PARAMETERS
  RANGE/ALT/HEADING/SPEED
- MAX / MIN LAUNCH RANGE
- WEAPONS STATUS

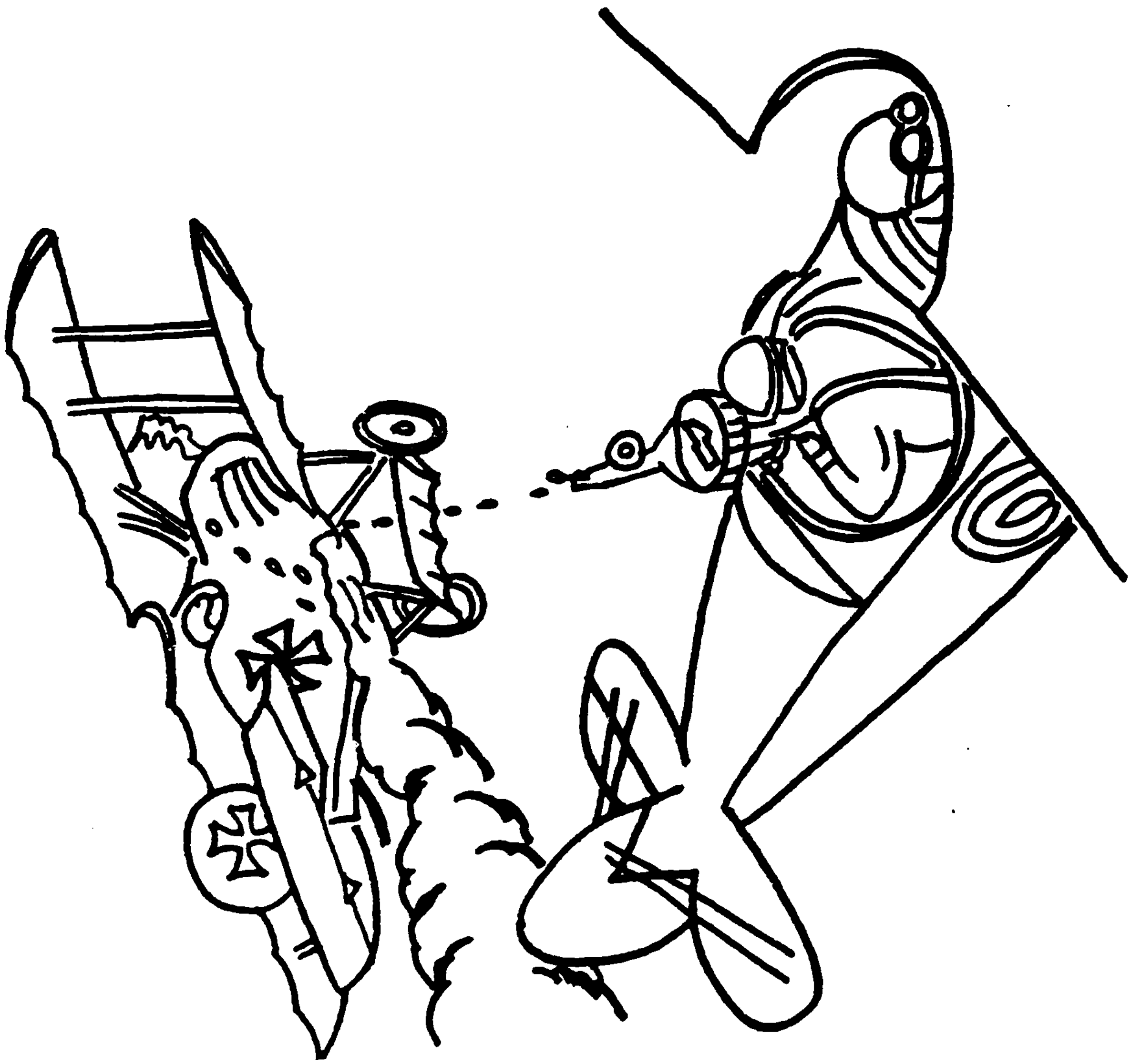
LAUNCH DATA

- ARMAMENT DATUM
- LINE-OF-SIGHT TO TARGET
- STEERING / STEERING ERROR
- MAX / MIN LAUNCH RANGE
- REAL TIME GUN SIGHT
- WEAPONS STATUS

LESS FREQUENT ESSENTIAL DATA

- SPEED
- ALTITUDE (Hp)
- HEADING
- FUEL REMAINING

- ANGLE-OF-ATTACK
- NORMAL LOAD FACTOR



USAF AIR SUPERIORITY AND INFORMATION DISPLAY

MAJOR JAMES BEATTY

A fighter pilot's requirements for information can be totally overwhelming. His aircraft systems are capable of completely deluging him with data. However, in many combat settings, such as the highly dynamic environment of a close-in air-to-air maneuvering engagement, his capabilities to comprehend that information are reduced. As range decreases pilots' tend to "tunnel" their mission and concentrate only on the target itself. This is a natural human reaction to focus all the "receptors" on the area of highest interest. The target is generally small and fast moving. The consequences of target information misinterpretation are quite grane so the natural reaction is to narrow the visual field of regard and also reduce the sensitivity to any other perception channel.

The problem for the designer then, is not to how to creat more information in the cockpit, but rather how to code, order, simplify and properly present it.

Slide 1 shows 26 essential elements of information needed by the F-15 pilot in air superiority. A rather lengthy list. What the average pilot could probably really benefit from however is a series of written commands that told him in increasingly stronger language, "Shoot now dumby!"

Slides 2, 3, & 4 list some data which is somewhere between the required and nice-to-know categories for missiles and guns in the air-to-air environment. Once again, many data bits that must/could be presented, the question is how best to insure the heavily task loaded pilot will perceive and correctly respond to it.

The time of more strict command/control and increased threat warning status capability is upon us. The Joint Tactical Information Display System (JTIDS) promises to give the aircrew an even greater amount of information in the cockpit. The future battle scenarios for mixed fighter forces working with the AWACS demand a novel approach to information display concepts, particularly in the single seat fighter cockpit. Slides 5 and 6 comprise a relatively current shopping list of information the pilot could certainly make good use of in the beyond visual range intercept or the ground attack/close air support/interdiction role. As can be seen, our age of sophisticated warfare and technological ability to produce information has offered a distinct possibility that the pilot will be swamped with information which he probably will not be able to use if it is not properly formatted, and logically presented in an optimal location.

The key to the research and development efforts should be based on these questions:

What is the value to the pilot of the proposed informaticn?

Is the displayedinformation appropriate to themission phase (segment)?

What quantity of information is needed?

Are the pilot/control interactions compatible with fast, straight forward interaction?

Will the displayeddnformation be correctly perceived and interpreted?

1. HORIZON LINE
2. PITCH LADDER
3. ROLL INDICATION
4. HEADING SCALE
5. ALTITUDE
6. AIR SPEED
7. "G"
8. AOA
9. ASE CIRCLE
10. STEERING DOT
11. RANGE SCALE
12. TGT RANGE
13. TGT RANGE RATE
14. R MAX 1
15. R MAX 2
16. R MIN
17. TYPE MISSILE SELECTED
18. QUANTITY REMAINING
19. AOJ/HOJ/JAM
20. HOLD ALTITUDE
21. SHOOT QUE
22. TGT DESIGNATOR BOX
23. TGT ALTITUDE
24. TGT AIR SPEED
25. TGT ASPECT ANGLE
26. FRIEND OR FOE

AIR-TO-AIR (IVR) DISPLAY REQUIREMENTS

LEAD COMPUTING OPTICAL SIGHT (LCOS)

- VELOCITY VECTOR
- BREAKAWAY
- WARNING INDICATOR
- BINGO FUEL
- AIRSPEED
- ANGLE OF ATTACK
- ALTITUDE
- CLOSURE VELOCITY
- RANGE TO TARGET
- GUN BORESIGHT/ARMAMENT DATUM LINE
- AIMING RETICLE
- ROUNDS REMAINING
- WEAPON STATUS
- STANDBY RETICLE
- TARGET DESIGNATOR/RADAR LOCK-ON
- ENERGY MANEUVERABILITY DISPLAY
- BULLET TIME OF FLIGHT @ 1 SEC
- NORMAL ACCELERATION
- FUEL QUANTITY (AFTER BINGO)
- CORNER VELOCITY DIRECTOR
- RHAW WARNING

AIR-TO-AIR (IVR) DISPLAY REQUIREMENTS (CONT.)

TRACER GUNSIGHT

- BREAKAWAY
- WARNING INDICATOR
- BINGO FUEL
- AIRSPEED
- ANGLE OF ATTACK
- ALTITUDE
- CLOSING VELOCITY
- RANGE
- GUN BORESIGHT/ARMAMENT DATUM LINE
- TRACER LINE
- STADIMETRIC RANGE BARS
- ROUND REMAINING
- ORDNANCE STATUS
- TARGET DESIGNATOR/RADAR LOCK-ON
- ENERGY MANEUVERABILITY DISPLAY
- TIME OF FLIGHT @ 1 SEC
- NORMAL ACCELERATION
- TOTAL FUEL AFTER BINGO
- CORNER VELOCITY DIRECTOR
- RHAW WARNING

OTHER GUNSIGHTS

- ESSENTIALLY SAME AS TRACER AND LCOS
- SYMBOLOGY FOR PARTICULAR SIGHT

AIR-TO-AIR (IVR) DISPLAY REQUIREMENTS (CONT.)

MISSILES (IVR)

- BREAKAWAY
- WARNING INDICATOR
- BINGO FUEL
- HEADING
- AIRSPEED
- ALTITUDE
- CLOSING VELOCITY
- RANGE TO TARGET
- GUNBORESIGHT/ARMAMENT DATUM LINE
- AIMING RETICLE
- ORDNANCE STATUS
- STANDBY RETICLE
- STEERING DOT
- TARGET DESIGNATOR/RADAR LOCK-ON
- MISSILE SEEKER POSITION
- ENERGY MANEUVERABILITY DISPLAY
- UNCAGE CUE
- MISSILE LAUNCH ZONE (R_{MIN} R_{MAX})
- TARGET LOCATION LINE AND ANGLE
- NORMAL ACCELERATION
- TOTAL FUEL AFTER BINGO
- TARGET ACCELERATION (G)
- ASPECT ANGLE
- MISSILE TRACKING CUE (MISSILE LOCK-ON TO TGT)
- CORNER VELOCITY DIRECTOR
- RHAW WARNING

9" Scope

1. 3 colors - 2 minimum Red Blue (Yellow)

2. Enemy Aircraft

a. Type
WHEN b. Armament (lethal cone)
REQ'D c. Maneuvering/ non maneuvering
d. Hdg alt airspeed (INKCAS)

3. Enemy SAM/AAA

a. Type
WHEN b. Lethal range
REQ'D c. Activity status
d. Target

4. Enemy Naval Forces

WHEN a. Type
REQ'D b. Armament (lethal range)
c. Status

5. Enemy Ground

WHEN a. Location
REQ'D b. Status/Armor - Troops
e. Miscellaneous - whatever clandestine intell can give us.

6. FEBA

WHEN a. Location
REQ'D b. Trend
c. Weather

7. Target Area

a. Target location
WHEN b. Target type
REQ'D c. FAC availability
d. Enemy ground/SAM/AAA/aircraft
e. Friendly ground/SAM/AAA/aircraft
f. Target area weather

8. Intercept Area

a. Aircraft Aired to
b. Time to intercept
c. Type target
d. Target armament

9. "Designated" Area

    a. Any enemy activity
    b. weather
    c. Friendly activity
    d. Easy selection of area

10. Friendly Aircraft

    a. Type
    b. Mission related
    c. Activity (tanker)

11. Friendly SAM/AAA

    a. General Type
    b. Location
    c. Activity

12. Friendly Ground

    a. Type
    b. Location
    c. Activity

13. Friendly Naval

    a. Type
    b. location
    c. Activity

14. Unknown/Unidentified

    a. Aircraft
    b. Ground
    c. SAM/AAA
    d. Navy

15. Message Reception

    a. Easily readible alpha-numerics
    b. Limited memory of msgs
    c. Easy recall of msgs

16. Message Transmission

    a. Easy formulation of msg
    b. Flexibility
    c. Easy means of transmission
    d. Capable of directing other aircraft, i.e., direct air battle from fighte

17. Base Status

    a. Weather
    b. Active
    c. Hostile activity

COCKPIT INFORMATION REQUIREMENTS - COMMON ELEMENTS

MAJOR ROBERT J. MCCUSKER

The requirement for advances in cockpit displays has been recognized for many years. Display methodology however, has not kept pace with advances in aircraft structure and power plant technologies - nor has it remained abreast of the National Airspace Systems. Fortunately, advancing display and computer technology is yielding the capability to begin with the entire foreward portion of the cockpit, including the windscreen, as a blank drawing board and to present specifically what the pilot needs to accomplish various mission segments - normal or combat. It is essential to make full use of the design flexibility which is inherent in this capability, both to provide better displays for the pilot and to permit future changes as unforeseen mission requirements dictate.

With properly designed displays, the capacity to conduct all-weather operations is within reach, a capability that is particularly critical for the military role. To realize this capability, not only must displays of position, projected position and time factor be provided, but sensor abilities must be improved to present literal real world imagery. This will require improvements in current IR and KU/KA bend radar systems. The possibility of a multi-spectral approach should be fully explored such that an on-instrument to touchdown approach may be executed as routinely as we presently conduct visual landings. I'm not going to discuss specific displays, however, I must mention that when I said "on-instrument", I was not necessarily indicating in-cockpit displays. The entire forward portion of the cockpit, including the windscreen, must be used. The charter given me was not to discuss displays, but to attempt to quantify what "information" must be available to efficiently operate todays and tomorrows high performance aircraft within an environment, which although presently very complex, will be even more so in the future. Cockpit information content may well be the point at which engineers and designers have stumbled in the past by not examining exactly what is needed by a pilot and/or taking advantage of the latest technology in presently this information to him. Several years ago, I was researching a related subject and had the opportunity to photograph cockpits of various aircraft ranging from WWI vintage to the latest research vehicles. The most striking factor was that the instrument panel of the F-51 and P-47 looked almostly exactly like the F-100 and bore a remarkable resemblance to the XB-70/B-58/F-4 generation. To be sure, color had been added to displays, but not an awful lot more. The information requirements I will outline are applicable to all design series and mission types of aircraft. No matter what the intended purpose of the airframe, it must take off, climb, cruise to a distination or target area and return to land. Additionally, most systems will operate for in excess of 95% of their like span within the National Airspace System. Therefore, it is not satisfactory to expend a great deal of money and effort to develop attack systems and then rely upon traditional instrumentation of basic aircraft control. For lack of a more original approach, I have broken the mission segments down into four basic areas for discussion: Common Elements (applicable to all phases of flight), Takeoff, Climb-Cruise-Descent, and Approach and Landing.

COMMON ELEMENTS

Annunciation - A great deal of improvement could be obtained by presenting the pilot with clear annunciation of which communication and navigation radio is being used and by providing the capability to pre-select frequencies and then call them up as active with a single action. This is not the same as twenty or so pre-set channels now available on some military UHF radios, but rather, the ability for the pilot to select the next desired frequency as he receives it from the controllers, etc., without disturbing the radio frequency being used. Clear, virtually instinctive annunciation of the Flight Director mode and autopilot level of indenture is also required. Failure warning could be much improved. As a suggestion, the standard work-caution panel which the pilot refers to in determining what generally has failed, could be replaced with a small, dedicated cathode-ray tube or liquid crystal display area on the instrument panel. This could save substantial panel space as well as presenting corrective action steps to the pilot. After assimilating the information and taking corrective action, the display could either be cleared mannually or automatically.

POSITION INFORMATION - Increasing sophisticated guidance systems such as MLS are demanding additional in cockpit information to permit the pilot to fully utilize the systems potential. In addition to course guidance and distance, items such as which way point or fix is being used as a reference, time to specified positions within a terminal area and suitable command steering information for curved approach paths must be devised. Probably the most significant element here is time to selected positions. Traditionally, pilots have mentally computed their arrival times at various positions or relied upon ground vectoring to obtain spacing. Increasing terminal area traffic densities are requiring much more accurate four dimentional positional information. In the not too distant future, the ability to quickly and accurately determine time elements relative to an approach zone may be a requirement much as transponders and communications radios are now.

ALTITUDE - As an adjunct to calibrated altitude, absolute altitude is a necessity. This information should be presented, as a minimum, below some pre-selected level which may vary depending upon mission profiles. For transport category, 2500-3000 feet and possibly much higher for fighter attack aircraft due to the higher vertical rates generated.

SPEED - With existing technology, calibrated airspeed should always be available to the pilot. True airspeed and ground speed should be a selectable display element, if not continuously displayed. The historical approach which has been computed so as to make good a calibrated airspeed which in turn yields a given true airspeed in order to achieve a desired ground speed. This truly constitutes an inaccurate, burdensome procedure at best.

VERTICAL RATE - The vertical velocity indicator used in the majority of present day aircraft is basically the same design as that of WWII. As a minimum, pitch augmented rate (instantaneous vertical velocity) should be provided. However, with the advent of more accurate instrumentation, the parameter of flight path angle (FPA) is presentable in usable form. The practice of attempting to establish a vertical speed which in combination with forward velocity, corrected for wind, will provide a desired path through the air mass is archaic to say the least. Displaying FPA is therefore both more direct and accurate. As an example of its use, when inter-

cepting a precision approach glide slope, the pilot simply establishes a FPA equivalent to the glide slope angle. Simple, direct, less burdensome and therefore safer.

TAKEOFF

ENGINE PERFORMANCE - Total engine performance monitoring can be accomplished using computers for the task of integrating and assessing data. For example, many current installations use engine RPM only as a general limit monitoring device. Other than this function, it serves little useful purpose to the pilot, yet valuable instrument panel space is devoted to tachometers and similar engine monitoring instruments. RPM, oil pressure, power output, etc. should be monitored electronically and the pilot provided information relative to out of tolerance conditions and appropriate corrective action. This form of logic lends itself to dedicated CRT or liquid crystal displays. Dedicating scarce panel space to the multitude of engine monitoring systems is simply no longer a feasible luxury. Further rationale is that many pilots who have experienced gradual failures will freely admit that their first noted indication was illumination of the master caution light, not gradually changing instrument indications.

AIRCRAFT PERFORMANCE - Assessment of aircraft performance during the take-off phase is truly an insurmountable task. Rules of thumb, personal techniques and frequent erroneous decisions abound. Once again, sophiscated sensors and computers can be assigned the task of monitoring, collating, and then presenting meaningful cues to the pilot. The increased accuracy of real time measurement of ambient temperature, density altitude, longitudinal acceleration, etc. militate strongly towards this approach. Information presented would then be failure annunciation incorporating degradation level and an abort continue decision for the pilot to act upon.

To achieve a reliable low visibility capability, runway alignment and deviation from centerline must be presented as both raw and command steering information.

CLIMB - CRUISE - DESCENT

BASIC REQUIREMENTS - Navigation guidance in both raw and command fore-mats should be provided in the lateral and vertical planes as well as in the longitudinal direction. This form of information should present the pilot with his potential for increased climb angle, speed potential, and action necessary to meet desired parameters such as altitudes at specific fixes, arrival times, etc. Additionally, angle of attack information should be presented in either raw or prossessed form so that the pilot may attain optimum climb performance (angle or rate) and cruise efficiency for both normal or engine out conditions. Attitude information must contain raw bank attitude as well as command steering. It is suggested that flight path angle be substituted for pitch attitude. In reality, a specific FPA is what the pilot is attempting to establish by varying the pitch attitude, angle of attack, true airspeed relationship. FPA would also provide the basis for selecting descent profiles to obtain maximum range or meet altitude restrictions at specific fixes. Transition to FPA display as opposed to raw pitch attitude poses no problems which cannot be overcome through

familiarization and inclusion of command pitch steering for those isolated maneuvers requiring fixed pitch attitudes. Those few operators who have been exposed to the concept (A-7 HUD) are totally convinced that it is far better than anything they have flown.

APPROACH-LANDING

The USAF Instrument Pilot Instructor School conducted extensive studi-s to define the "real-world" low visibility environment during the pilot factors portion of the SST program. I drew heavily upon these studies and upon personal experience during later low visibility landing studies in which I participated while assigned to the unit. The problem of precisely controlling aircraft for landing divides naturally intwo two general categories: Vertical path guidance and Lateral path guidance. The latter is the most difficult due to the dynamics of the situation. Consider that changes in pitch attitude relate closely to vertical rates and thereby to glideslope control. In the Lateral control area, a deviation is noted, whether due to an inaccurate heading or wind shear, which necessitates a bank input to change heading and finally begin the actual correction back to the centerline. Hense the general division into the two broad categories.

General information required is calibrated pressure altitude in conjunction with absolute altitude. Absolute altitude should be both quantitative as a basis for decision making and qualitative if it is to be used for on-instrument landings. Qualitative absolute altitude will provide the pilot with a "feel" for distance above the runway as opposed to pure numerical altitude. Angle of attack information should be used as the basis for "speed" control as it is far more accurate in terms of actual aircraft performance relative to changing gross weights, configurations, etc. If automatic flight controls (AFCS) are involved, which they most certainly will be if a low visibility capability is desired, annunciation of the AFCS function stepping and the provision for manual sequencing must be available.

VERTICAL PATH GUIDANCE - Glide slope information and error, pitch attitude and vertical rate or; themore desirable parameter flight path angle, must be presented in clear, easily interpretable form. Ideally, some display of project touchdown point and command steering to include the large maneuver are essential.

LATERAL PATH GUIDANCE - Error from centerline must be displayed in terms which are meaningful to the pilot. This basically means that deviation should be presented in linear as opposed to angular terms. Additionally, provisions must be made for displaying lateral rate and the maximum acceptable amount of deviation and rate which the specific airframe can tolerate within the constraint of the particular runway width.

Command steering must be continued into the post touchdown stage to provide rollout information. If truly low visibility operations are to

become a reality, a means of assessing approach progress totally independent of the instrument landing aid in use must be available. This Independent Landing Monitor must duplicate much of the previously mentioned information so that the pilot can check his approach path and projected touchdown point relative to the runway environment at a glance, hense, symbology must be instinctive.

Technology is at hand to accomplish these goals and provide the pilot with the specific information needed to conduct a particular mission phase. The cost of pre-planning and development will more than be offset by increased operational capability and effectiveness.

INFORMATION REQUIREMENTS ATTACK MISSION

CAPT SCHOEFFEL

INFORMATION REQUIREMENTS
ATTACK MISSION

I. Objective: To determine

A. What is to be displayed

1. by class of information, in a feedback loop context i.e.

a. Detection

b. Assessment

c. Interaction

by

2. Prioritization

a. Minimum for survival

b. Enhancement of safety

c. Minimum for mission accomplishment

d. Enhancement of mission accomplishment

B. How it is to be displayed

1. By sensory channel

a. Aural

(1) pitch

(2) verbal

(3) signal frequency

b. Tactile

(1) shape/position (of knobs)

(2) vibration/motion

c. Visual

(1) Method of presentation

(a) Direct view (PPI, LED, Liquid Crystal, plasma panel, storage tube, etc.)

(b) Virtual or projected image (HUD, holographic lens, etc.)

(2) Format

(a) Qualitatively

i. rate stoppage, size

ii. color/hue

iii. on/off (binary) symbolic state

(b) Parametrically

i. digital

ii. indicator

a. Dial

b. Linear "tape"

(c) Graphically

i. Viewpoint

a. Horizontal--plan view

b. Vertical--forward view

c. Vertical--profile view

d. Isometric or Perspective

ii. Degree of Coding/Abstraction

a. Pictorial

b. Skeletonized

c. Symbolic

C. Where it is to be displayed

1. Heads Up (visual)

2. Heads Down (visual)

3. Unrelated (tactile, aural)

D. When it is to be displayed

1. Sequence

a. Priority and preemption

b. Sharing of space and time

c. Duration of display (if sequenced)

2. Interaction/Interface of Displays

a. All eventually hand back to a direct bio-sensing of external world.

b. Interference may be by

(1) Obscuration/rivalry (visual, aural and physical)

(2) Focal plane difference

(3) Light hue sensitivity/acuity difference

(4) Brilliance and adaptation problems

c. Interference may be with

(1) Pilot mobility (and direct biosensing or control actuation)

(2) Pilot comprehension/perception

(3) Escape/survival/environmental systems (operation of other systems)

II. Attack Mission

A. Definition:

"The destruction/neutralization of enemy land or maritime targets by means of a manned aircraft under varying conditions of environmental hazard and enemy threat." GOR #11 defines airborne attack as consisting of:

1. Defense Suppression
2. Offense/Defense Destruction
3. Close Air Support
4. Interdiction
5. Strategic Support

B. Mission requirements (as a detailed list of required/desired actions).

1. Under normal conditions:
   a. Aircraft configuration monitoring
   b. Aircraft configuration assessment
   c. Aircraft configuration correction
   d. Aircraft structural, aerodynamic, and stability limitation parameter monitoring
   e. Aircraft structural, aerodynamic, and stability limitations match assessment
   f. Aircraft structural, aerodynamic, and stability limitation avoidance consideration/action
   g. Engine measurement (performance and condition)
   h. Engine assessment (performance and condition)
   i. Engine correction/control (condition only?)

g. Energy optimization monitoring

h. Energy optimization mismatch assessment

i. Energy optimization consideration/action

j. Aerodynamic performance measurement

k. Aerodynamic performance assessment

l. Aerodynamic performance correction

m. Aircraft subsystems monitor (hydraulic, NAVWEPS, fuel, etc.)

n. Aircraft subsystems assessment

o. Aircraft subsystems control/correction

p. Coordination

(1) control signal monitor

(2) control signal assessment

(3) control signal acceptance/rejection

(4) communications monitor

(5) communications assessment

(6) communications control

q. Traffic detection

r. Traffic location

s. Traffic relative location assessment

t. Traffic hazard assessment

u. Traffic hazard avoidance/adjustment

v. Environmental hazard detection

w. Environmental hazard assessment

x. Environmental hazard avoidance

y. Route selection

z. Route deviation assessment

aa. Route deviation correction

bb. Threat detection

cc. Threat location

dd. Threat evaluation

ee. Threat counter

ff. Threat countermeasure system monitoring

gg. Threat countermeasure system selection

hh. Threat countermeasure system employment

ii. Possible target detection

jj. Possible target location

kk. Target classification

ll. Target selection (prioritization?) from clutter background

mm. Target designation to weapon system

nn. Weapons readiness monitoring

oo. Weapon readiness control

pp. System readiness monitoring

qq. System readiness control

rr. Weapon launch position/time selection

ss. Weapon launch position/time deviation assessment

tt. Weapon launch position/time deviation correction

uu. Weapon selection

vv. Total weapon system readiness

ww. Weapon launch

xx. Weapon post-launch control

yy. Data storage

(1) of damage assessment information

(2) of threat information

(3) of target information

(4) of fault isolation information

(5) of aircraft safety parameters

(6) of final weapon delivery parameters

zz. Data retrieval

(1) of damage assessment information

(2) of threat information

(3) of target information

(4) of fault isolation information

(5) of aircraft safety parameters

(6) of final weapon delivery parameters

2. Under abnormal conditions:

a. Aircraft damage/malfunction detection

b. Aircraft damage/malfunction assessment

c. Aircraft damage/malfunction correction

d. Survival/escape system monitoring

e. Survival/escape system readying

f. Survival/escape system actuation

g. Aircraft abnormal flight assessment/ correction

. From the actions list is derived a list of:

3. Normal information categories

    a. Aircraft configuration
    b. Engine
    c. Aircraft attitude
    d. Aerodynamic performance
    e. Aircraft maneuver energy
    f. Aircraft limitations
    g. Aircraft subsystems
    h. Control signal (from external sources)
    i. Communications (internal and external)
    j. Traffic
    k. Environmental hazard
    l. Route
    m. Threat
    n. Threat countermeasures
    o. Target
    p. Weapon
    q. Fire control
    r. Weapon control
    s. Data storage
    t. Data retrieval

4. Abnormal information categories

    a. Damage/malfunction
    b. Survival/escape
    c. Abnormal flight

Which is broken down into

C. General modes of information:

1. Detection
2. Assessment
3. Reaction/interaction

D. The information is derived in levels concerning:

1. the external world
2. aircraft performance relative to the external world
3. internal operation of the aircraft and its subsystems

III. Mission Phases and Associated Information for Display Categories

A. Pre-flight (not analyzed here)

B. Takeoff (not analyzed here)

C. Climb (not analyzed here)

D. ARTC (not analyzed here)

E. Navigation to target area, high altitude (i.e., above ground interference)

1. Phase required/desired information

a. Configuration

b. Engine

c. Damage/malfunction

d. Aircraft limitations

e. Aircraft cruise energy

f. Aerodynamic performance

g. Aircraft attitude control

h. Environmental hazard

i. Communications

j. Traffic

k. Route/time

l. Subsystems

m. Survival/escape

n. Weapon

o. Data storage

2. Phase required/desired action displays -- phase timing; priorities: [Survival, Safety, Mission Essential, Mission Enhancing]

a. Configuration - Safety

(1) monitor - until satisfactory

(a) channel - redundant tactile/visual

(b) format - redundant parametric/graphic (symbolic)

(c) location - HD on subsystem display (fwd)

(d) method - direct view

(2) assessment - until matched -- all categories the same as monitor

(3) correction - by completion of display time

(a) channel - as for monitor

(b) format - as for monitor plus blink(?)

(c) location - as for monitor

(d) method - as for monitor

(4) malfunction - autotrigger monitor until corrected or overridden

(a) channel - as for monitor

(b) format - as for monitor; blink

(c) location - as for monitor plus HUD plus EMERG

(d) method - as for monitor

b. Engine Performance - Mission Essential

(1) monitor - on call until deselected

(a) channel - visual

(b) format - parametric digit/tape

(c) location - HD subsystem display (fwd)

(d) method - direct view

(2) assessment - coincident with monitor -- all categories the same as monitor

(3) correction - inherent in monitor -- NA

c. Aerodynamic Performance - Safety

(1) monitor - continuous for all but angle of attack; angle of attack -- when selected until deselected + autotriggered near preselected limit.

(a) channel

i. air speed, altitude, G, vertical velocity - visual

ii. angle of attack - visual (selectable) plus audio (near limit)

(b) format

i. parametric linear, symbolic

ii. symbolic plus signal frequency

(c) location - selectable to HUD, HD fwd

(d) method - HUD projection, direct

(2) assessment - continuous/inherent in monitor

(a) channel - visual plus audio

(b) format

i. symbolic coincidence

ii. binary (off/on) audio

(c) location - same as for monitor

(d) method - same as for monitor

(3) correction - inherent in monitor -- NA

d. Route space/time (Mission Essential)

(1) monitor - continuous until deselected

(a) channel - visual

(b) format - graphic/map -- horizontal +(?) vertical fwd skeletonized

(c) location - HD central panel, HUD for time, $\dot{V}$, hdg

(d) method - holographic for map, HUD projector

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - qualitative for velocity

- rate stoppage
- parametric for time/dis/ hdg error
- symbolic for position difference (could do it all)

(c) location - as for monitor + vertical(?) HUD for parametrics, V rate stoppage, symbolic hdg

(d) method - holographic panel

(3) correction - coincident with assessment all categories same as for assessment

e. Environmental Hazard (e.g., Visibility, Hail, Icing, Turbulence) - Safety

(1) monitor - on call by category until deselected; selectably coincident with route monitor until deselected

(a) channel - visual

(b) format - symbolic and pictorial/ (terrain)

(c) location - HD central panel horizontal

(d) method - virtual

(2) assessment - during external control

(a) channel - as for monitor

(b) format - HUE

(c) location - as for monitor plus vertical

(d) method - as for monitor

(3) avoidance - inherent in/or coincident with monitor

(a) - (d) -- NA

f. Aircraft Limitations Criteria - Safety

(1) monitor - on call or autotrigger by preselected criteria; until deselected

(a) channel - visual

(b) format - graphic symbolic + alpha numeric; *blink if autotriggered*

(c) location - HD *forward if selected;* HUD if autotriggered

(d) method - direct view or projected

(2) assessment - coincident with monitor

(a) channel - visual

(b) format - graphic matching

(c) location - as for monitor

(d) method - as for monitor

(3) avoidance - same as for assessment

g. Cruise Energy Status - Mission Enhancing

(1) monitor - on call or autotriggered by preselected criteria; until deselected

(a) channel - visual

(b) format - parametric

(c) location - HD fwd

(d) method - direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - parametric comparison of desired and existing performance and results

(c) location - as for monitor

(d) as for monitor

(3) optimization/correction - coincident with assessment

(a) - (d) as for assessment

h. Aircraft Attitude Control - Aircraft Survival

(1) monitor - continuous

(a) channel - visual

(b) format - graphic symbolic + parametric

(c) location - HUD, HD vertical

(d) method - projected, direct

(2) assessment - during external control

(a) channel - as for monitor

(b) format - as for monitor

(c) location - as for monitor

(d) method - as for monitor

(3) correction - inherent in monitor

i. Traffic - Safety, Mission Enhancement

(1) detection - automatic continuous when within safety criteria;

- until deselected for preselected criteria
- inherent with avoidance -- on call, coincident with route monitor

(a) channel - visual

(b) format - binary, blink + graphic symbolic

(2) location - on call coincident with route monitor

(a) channel - as for detection

(b) format - binary (direction indicator) + graphic symbolic

(c) location - as for monitor

(d) method - as for monitor

(3) hazard assessment - automatic continuous within safety criteria until criteria invalid

(a) format - graphic symbolic

(b) correction - NA

(4) avoidance - automatic continuous within safety criteria until criteria invalid

(a) channel - as for monitor

(b) format - same as for monitor in general, but distinguishable (color/ size)

(c) location - as for monitor

(d) method - as for monitor

j. Survival/Escape - Safety

(1) monitor - on call until deselected; auto-triggered by safety and survival priority

(a) channel - visual

(b) format - binary (goes to graphic symbolic)

(c) location - HUD + HD vertical

(d) method - projected + direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - graphic symbolic/binary rate stoppage (matching)/size (qualitative)

(c) location - HUD, HD horizontal

(d) method - as for monitor

(3) correction - NA

k. Subsystems - Aircraft Survival (Attitude Control and Power Systems)

(1) monitor

(a) channel - visual

(b) format - parametric linear

(c) location - HD fwd, subsystem display area

(d) method - direct

(2) assessment - as for monitor

(3) correction - NA

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary (display) alpha

(c) location - EMERG + HD fwd subsystem display area + HD horizontal preempt by alpha

(d) method - direct

(5) aircraft attitude control

(a) malfunction - trigger display of malfunction and monitor until correction

(b) assessment - inherent in display

(c) correction - by deactivation of display

(6) electric/hydraulic/pneumatic power system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) correction - coincident w/malfunction

(d) malfunction - trigger display and trigger monitor; trigger correction until deselected or corrected

l. Subsystems - Safety

(1) monitor (for those with degree-of-operation differentiation - those that fail/operate are not monitored)

(a) channel - visual

(b) format - alpha

(c) location - subsystems panel, HD fwd

(d) method - direct

(2) assessment (for those that monitor)

(a) channel - as for monitor

(b) format - parametric linear + graphic symbolic alongside

(c) location - as for monitor

(d) method - as for monitor

(3) correction - (for those that monitor) -- NA

(4) malfunction (autotriggers monitor)

(a) channel - as for monitor

(b) format - binary blink + binary alpha display

(c) location - EMERG + HD fwd subsystems display area + direct display horizontal preempts by alpha, + HUD

(d) method - direct, projection

(5) aircraft limitations criteria detection/display - autotriggered until deselected

(6) damage/malfunction indicator system

(a) triggered, on call - until deselected

(7) engine system condition

(a) monitor - continuous until deselected; coincident w/performance correction

(b) assessment - coincident with monitor

(c) correction - coincident w/performance and correction

(8) fuel system

(a) monitor - on call until deselected and autotriggered by preselected criteria

(b) assessment - coincident w/monitor

(c) correction - coincident w/monitor

(d) malfunction/criticality - autotrigger; coincident autotrigger of monitor assessment and correction unless overridden

(9) cruise energy display

(a) malfunction - autotriggered until deselected

(10) internal environment system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) malfunction/criticality - autotrigger; coincident autotrigger of monitor and assessment until overridden

(11) traffic hazard system

(a) malfunction - autotrigger until deselected

(12) survival/escape system

(a) malfunction - autotrigger

(13) environmental hazard countermeasure system (anti-ice)

(a) malfunction - on call until deselected

m. Subsystems - Mission Essential

(1) monitor

(a) channel - visual (tactile-lighting)

(b) format

i. comm - parametric digital

ii. navigation - parametric alpha-numeric

iii. carriage/release - binary, color, alpha

iv. weapon - binary, color, alpha

v. targeting - alpha

vi. threat - alpha

vii. lighting - position

(c) location

i. comm/navigation - HU console or lower panel

ii. carriage/release - HU

iii. weapon - HU

iv. targeting - HUD, horizontal, vertical fwd display areas

v. threat - subsystems panel, console, panel

vi. lighting - on control

(d) method - direct

(2) assessment - not required (inherent in monitor)

(a) channel - as for monitor

(b) format

i. comm - NR

ii. navigation - NR

iii. weapon - binary, color

iv. targeting - NR

v. threat - NR

vi. lighting - NR

(c) location - as for monitor

(d) method - direct

(3) correction - inherent -- NR

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary alpha

(c) location - EMERG + HD fwd subsystem display area + HUD

(d) method - direct + HUD projected

(5) communications system

(a) monitor - continuous

(b) assessment - inherent in monitor

(c) correction - inherent in monitor

(6) navigation system

(a) monitor - on call until deselected

(b) assessment - inherent in monitor

(c) correction - until corrected

(d) malfunction - autotriggered

(7) carriage/release system

(a) monitor - continuous

(b) malfunction - autotriggered

(8) weapon

(a) monitor - continuous

(b) assessment - coincident with monitor

(c) correction - coincident with monitor until corrected

(9) targeting system

(a) monitor - continuous (?)

(b) malfunction - autotrigger and on call (BIT) until deselected

(10) threat analysis system

(a) monitor - on call until deselected

(b) malfunction - autotriggered

(11) lighting system

(a) monitor - not required

(b) assessment - not required

(c) correction - not required

(12) maneuver energy optimization

(a) monitor - not required

(b) malfunction - autotriggered

n. Subsystems - Mission Enhancement

(1) For all except Data Storage

(a) malfunction

i. channel - visual

ii. format - binary blink plus binary alpha

iii. location - EMERG + HUD + subsystems panel HD fwd

iv. method - direct

(b) correction

i - iv - as for malfunction

(2) External environment sensor system - autotrigger

(3) Control signal acceptance system - autotriggered

(4) Aerodynamic parameter monitor system -

(a) malfunction - autotrigger

(b) correction - state shown after deselection/malfunction

(5) Threat countermeasures - autotriggered

(6) Security - autotrigger

(7) Data Storage

(a) monitor - when selected until deselected

i. channel - visual

ii. format - binary alpha

iii. location - subsystem panel HD fwd

iv. method - direct

(b) assessment/malfunction - on call until deselected

F. Phase: Target/Threat Area, High Altitude

1. Required/Desired Information

a. Phase Required/Desired Information

(1) Configuration

(2) Engine

(3) Damage/malfunction

(4) Aircraft Limitation

(5) Aircraft Cruise Energy

(6) Aerodynamic Performance

(7) Aircraft Attitude Control

(8) Environmental Hazard

(9) Communications

(10) Traffic

(11) Route/Time

(12) Subsystems

(13) Survival/Escape

(14) Weapon

(15) Data Storage

(16) Control Signal

(17) Threat

(18) Aircraft Maneuver Energy

(19) Target

2. Phase Required/Desired Action Displays

a. Configuration - Safety

(1) monitor - until satisfactory

(a) channel - redundant tactile/visual

(b) format - redundant parametric/graphic (symbolic)

(c) location - HD on subsystem display (fwd)

(d) method - direct view

(2) assessment - until matched -- all categories the same as monitor

(3) correction - by completion of display time

(a) channel - as for monitor

(b) format - as for monitor plus blink(?)

(c) location - as for monitor

(d) method - as for monitor

(4) malfunction - autotrigger monitor until corrected or overridden

(a) channel - as for monitor

(b) format - as for monitor; blink

(c) location - as for monitor plus HUD plus EMERG

(d) method - as for monitor

b. Engine Performance - Mission Essential

(1) monitor - on call until deselected

(a) channel - visual

(b) format - parametric digit/tape

(c) location - HD subsystem display (fwd)

(d) method - direct view

(2) assessment - coincident with monitor -- all categories the same as monitor

(3) correction - inherent in monitor -- NA

c. Aerodynamic Performance - Safety

(1) monitor - continuous for all but angle of attack; angle of attack -- when selected until deselected + autotriggered near preselected limit.

(a) channel

i. air speed, altitude, G, vertical velocity - visual

ii. angle of attack - visual (selectable) plus audio (near limit)

(b) format

i. parametric linear, symbolic

ii. symbolic plus signal frequency

(c) location - selectable to HUD, HD fwd

(d) method - HUD projection, direct

(2) assessment - continuous/inherent in monitor

(a) channel - visual plus audio

(b) format

i. symbolic coincidence

ii. binary (off/on) audio

(c) location - same as for monitor

(d) method - same as for monitor

(3) correction - inherent in monitor -- NA

d. Route Space/Time (Mission Essential)

(1) monitor - continuous until deselected

(a) channel visual

(b) format - graphic/map -- horizontal +(?) vertical fwd skeletonized

(c) location - HD central panel, HUD for time, V, hdg

(d) method - holographic for map, HUD projector

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - qualitative for velocity
- rate stoppage
- parametric for time/dis/hdg error
- symbolic for position difference (could do it all)

(c) location - as for monitor + vertical(?) HUD for parametrics, V rate stoppage, symbolic hdg

(d) method - holographic panel

(3) correction - coincident with assessment all categories same as for assessment

e. Environmental Hazard (e.g., Visibility, Hail, Icing, Turbulence) - Safety

(1) monitor - on call by category until deselected; seletably coincident with route monitor until deselected

(a) channel - visual

(b) format - symbolic and pictorial/ (terrain)

(c) location - HD central panel horizontal

(d) method - virtual

(2) assessment - during external control

(a) channel - as for monitor

(b) format - HUE

(c) location - as for monitor plus vertical

(d) method - as for monitor

(3) avoidance - inherent in/or coincident with monitor

(a) - (d) -- NA

f. Aircraft Limitations Criteria - Safety

(1) monitor - on call or autotrigger by preselected criteria; until deselected

(a) channel - visual

(b) format - graphic symbolic + alpha numeric; blink if autotriggered

(c) location - HD forward if selected; HUD if autotriggered

(d) method - direct view or projected

(2) assessment - coincident with monitor

(a) channel - visual

(b) format - graphic matching

(c) location - as for monitor

(d) method - as for monitor

(3) avoidance - same as for assessment

g. Cruise Energy Status - Mission Enhancing

(1) monitor - on call or autotriggered by preselected criteria; until deslected

(a) channel - visual

(b) format - parametric

(c) location - HD fwd

(d) method - direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - parametric comparison of desired and existing performance and results

(c) location - as for monitor

(d) as for monitor

(3) optimization/correction - coincident with assessment

(a) - (d) as for assessment

h. Aircraft Attitude Control - Aircraft Survival

(1) monitor - continuous

(a) channel - visual

(b) format - graphic symbolic + parametric

(c) location - HUD, HD vertical

(d) method - projected, direct

(2) assessment - during external control

(a) - (d) as for monitor

(3) correction - as for monitor

i. Traffic - Safety, Mission Enhancement

(1) detection - automatic continuous when within safety criteria;

- until deselected for preselected criteria

- inherent with avoidance -- on call, coincident with route monitor

(a) channel - visual

(b) format - binary, blink + graphic symbolic

(2) location - on call coincident with route monitor

(a) channel - as for detection

(b) format - binary (direction indicator) + graphic symbolic

(c) location - as for monitor

(d) method - as for monitor

(3) hazard assessment - automatic continuous within safety criteria until criteria invalid

(a) format - graphic symbolic

(b) correction - NA

(4) avoidance - automatic continuous within safety criteria until criteria invalid

(a) channel - as for monitor

(b) format - same as for monitor in general, but distinguishable (color/size)

(c) location - as for monitor

(d) method - as for monitor

j. Survival/Escape - Safety

(1) monitor - on call until deselected; auto-triggered by safety and survival priority

(a) channel - visual

(b) format - binary (goes to graphic symbolic)

(c) location - HUD + HD vertical

(d) method - projected + direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - graphic symbolic/binary rate stoppage (matching)/size (qualitative)

(c) location - HUD, HD horizontal, ~~THREAT~~

(d) method - as for monitor

(3) correction - NA

k. Maneuver Energy - Mission Enhancing

(1) monitor - on call until deselected

(a) channel - visual

(b) format - qualitative graphic

(c) location - HUD

(d) method - projection

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - coincidence/difference of graphics

(c) location - as for monitor

(d) method - as for monitor

(3) optimization - coincident with monitor

(a) - (d) as for assessment

l External Control - Mission Enhancement

(1) monitor - on call during control until deselected

  i. channel - visual

  ii. format - parametric, dial(C_n) + linear(V); graphic symbolic (C_n+El)

  iii. location - HUD, central panel horizontal and vertical - route space/time display

  iv. method - projected (HUD) + direct

(2) assessment - by coincident display of goal control path info

  i. same as monitor

(3) malfunction - inherent in monitor (see subsystem)

m Threat - Aircraft Survival

(1) detection - autotriggered until criteria invalid or overridden

  i. channel - redundant audio + visual

  ii. format - color + relief, symbolic, audio signal frequency

  iii. location - HUD, HD vertical and horizontal

  iv. method - direct + indirect projection

(2) location - autotriggered coincident with detection, coincident with route display

i. - iv. same as for detection

(3) evaluation/avoidance - autotriggered until overridden

i. channel - visual

ii. format - color + binary (flash) + graphic

iii. location - same as "detection"

iv. method - indirect + holographic

n. Threat Countermeasures - Mission Enhancing

(1) monitor

i. channel - visual

ii. format - alpha binary + color

iii. location - HD subsystem panel

iv. method - direct

(2) CM system selection - same as monitor plus

ii. format - same

iii. location - HU + HD subsystem panel

iv. method - projection plus direct

(3) CM system employment - same as monitor plus

ii. format - alpha binary + blink + color

o. Target - Mission Essential

(1) possible target detection - continuous with route

(a) channel - visual

(b) format - color + symbolic

(c) location - HUD + HD horizontal + vertical(?)

(d) method - holographic + indirect

(2) possible target location - continuous when derived, coincident with route

(a) - (d) same as for detection

(3) target ID - when derived until overridden, coincident with location

(a) channel - visual

(b) format - color, symbolic heightened relief

(c) location - same as detection

(d) method - same as detection

p. Threat Countermeasures - Mission Enhancing

(1) monitor

(a) channel - visual

(b) format - alpha binary + color

(c) location - HD subsystem panel

(d) method - direct

(2) CM system selection - same as monitor plus

(a) channel - visual

(b) format - same

(c) location - HU +HD subsystem panel

(d) method - projection plus direct

(3) CM system employment - same as monitor plus

(a) channel - visual

(b) format - alpha binary + blink + color

q. Subsystems - Aircraft Survival (Attitude Control and Power Systems)

(1) monitor

(a) channel - visual

(b) format - parametric linear

(c) location - HD fwd, subsystem display area

(d) method - direct

(2) assessment - as for monitor

(3) correction - NA

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary (display) alpha

(c) location - EMERG + HD fwd subsystem display area + HD horizontal preempt by alpha

(d) method - direct

(5) aircraft attitude control

(a) malfunction - trigger display of malfunction and monitor until correction

(b) assessment - inherent in display

(c) correction - by deactivation of display

(6) electric/hydraulic/pneumatic power system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) correction - coincident w/malfunction

(d) malfunction - trigger display and trigger monitor; trigger correction until deselected or corrected

r. Subsystems - Safety

(1) monitor (for those with degree-of-operation differentiation - those that fail/operate are not monitored)

(a) channel - visual

(b) format - alpha

(c) location - subsystems panel, HD fwd

(d) method - direct

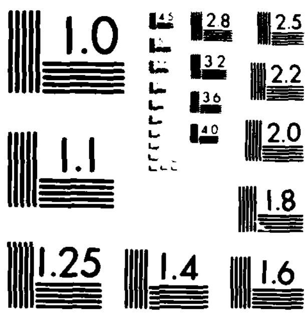
(2) assessment (for those that monitor)

(a) channel - as for monitor

AD-A097 285 NAVAL AIR TEST CENTER PATUXENT RIVER MD F/G 5/8
ADVANCED AIRCREW DISPLAY SYMPOSIUM (3RD), 19-20 MAY.(U)
1976

UNCLASSIFIED NL

2 of 5
AD
A097285



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963 A

(b) format - parametric linear + graphic symbolic alongside

(c) location - as for monitor

(d) method - as for monitor

(3) correction - (for those that monitor) -- NA

(4) malfunction (autotriggers monitor)

(a) channel - as for monitor

(b) format - binary blink + binary alpha display

(c) location - EMERG + HD fwd subsystems display area + direct display horizontal preempts by alpha + HUD

(d) method - direct projection

(5) aircraft limitations criteria detection/ display - autotriggered until deselected

(6) damage/malfunction indicator system

  (a) triggered, on call - until deselected

(7) engine system condition

  (a) monitor - continuous until deselected; coincident w/performance correction

  (b) assessment - coincident with monitor

  (c) correction - coincident w/performance and correction

(8) fuel system

  (a) monitor - on call until deselected and autotriggered by preselected criteria

  (b) assessment - coincident w/monitor

  (c) correction - coincident w/monitor

  (d) malfunction/criticality - autotrigger; coincident autotrigger or monitor assessment and correction unless overridden

(9) cruise energy display

  (a) malfunction - autotriggered until deselected

(10) internal environment system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) malfunction/criticality - autotrigger; coincident autotrigger of monitor and assessment until overridden

(11) traffic hazard system

(a) malfunction - autotrigger until deselected

(12) survival/escape system

(a) malfunction - autotrigger

(13) environmental hazard countermeasure system (anti-ice)

(a) malfunction - on call until deselected

s. Subsystems - Mission Essential

(1) monitor

(a) channel - visual (tactile-lighting)

(b) format

i. comm - parametric digital

ii. navigation - parametric alpha-numeric

iii. carriage/release - binary, color, alpha

iv. weapon - binary, color, alpha

v. targeting - alpha

vi. threat - alpha

vii. lighting - position

(c) location

i. comm/navigation - HU console or lower panel

ii. carriage/release - HU

iii. weapon - HU

iv. targeting - HUD, horizontal, vertical fwd display areas

v. threat - subsystems panel, console, panel

vi. lighting - on control

(2) assessment - not required (inherent in monitor)

(a) channel - as for monitor

(b) format

i. comm - NR

ii. navigation - NR

iii. weapon - binary, color

iv. targeting - NR

v. threat - NR

vi. lighting - NR

(c) location - as for monitor

(d) method - direct

(3) correction - inherent -- NR

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary alpha

(c) location - EMERG + HD fwd subsystem display area + HUD

(d) method - direct + HUD projected

(5) communications system

(a) monitor - continuous

(b) assessment - inherent in monitor

(c) correction - inherent in monitor

(6) navigation system

(a) monitor - on call until deselected

(b) assessment - inherent in monitor

(c) correction - until corrected

(d) malfunction - autotriggered

(7) carriage/release system

(a) monitor - continuous

(b) malfunction - autotriggered

(8) weapon

(a) monitor - continuous

(b) assessment - coincident with monitor

(c) correction - coincident with monitor until corrected

(9) targeting system

(a) monitor - continuous (?)

(b) malfunction - autotrigger and on call (BIT) until deselected

(10) threat analysis system

(a) monitor - on call until deselected

(b) malfunction - autotriggered

(11) lighting system

(a) monitor - not required

(b) assessment - not required

(c) correction - not required

(12) maneuver energy optimization

(a) monitor - not required

(b) malfunction - autotriggered

t. Subsystems - Mission Enhancement

(1) For all except Data Storage

(a) malfunction

i. channel - visual

ii. format - binary blink plus binary alpha

iii. location - EMERG + HUD + subsystems panel HD fwd

iv. method - direct

(b) correction

i - iv - as for malfunction

(2) external environment sensor system - autotrigger

(3) control signal acceptance system - autotriggered

(4) aerodynamic parameter monitor system -

(a) malfunction - autotrigger

(b) correction - state shown after deselection/malfunction

(5) threat countermeasures - autotriggered

(6) security - autotrigger

(7) data storage

(a) monitor/operation (storage) - on call until deselected; by type of information; during storage

i. channel - visual

ii. format - binary alpha

iii. location - subsystem panel HD fwd

iv. method - direct

(b) malfunction - autotriggered

i. - iv. same as for monitor/ operation

(c) retrieval - on call for selectable threat and target information

i. - iv. same as for monitor/operation

G. Phase: Target/Threat Area, Low Altitude

1. Required/Desired Information

a. Phase required/desired information

(1) Configuration

(2) Engine

(3) Damage/malfunction

(4) Aircraft limitations

(5) Aircraft cruise energy

(6) Aerodynamic performance

(7) Aircraft attitude control

(8) Environmental hazard

(9) Communications traffic

(10) Traffic

(11) Route/time

(12) Subsystems

(13) Survival/escape

(14) Weapon

(15) Data storage

(16) Control signal

(17) Threat

(18) Aircraft maneuver energy

(19) Target

(20) Environmental hazard (geographic)

2. Phase required/desired action displays

a. Configuration - Safety

(1) monitor - until satisfactory

(a) channel - redundant tactile/visual

(b) format - redundant parametric/graphic (symbolic)

(c) location - HD on subsystem display (fwd)

(d) method - direct view

(2) assessment - until matched -- all categories the same as monitor

(3) correction - by completion of display time

(a) channel - as for monitor

(b) format - as for monitor plus blink (?)

(c) location - as for monitor

(d) method - as for monitor

(4) malfunction - autotrigger monitor until corrected or overridden

(a) channel - as for monitor

(b) format - as for monitor; blink

(c) location - as for monitor plus HUD plus EMERG

(d) method - as for monitor

b. Engine Performance - Mission Essential

(1) monitor - on call until deselected

(a) channel - visual

(b) format - parametric digit/tape

(c) location - HD subsystem display (fwd)

(d) method - direct view

(2) assessment - coincident with monitor -- all categories the same as monitor

(3) correction - inherent in monitor -- NA

c. Aerodynamic Performance - Safety

(1) monitor - continuous for all but angle of attack; angle of attack -- when selected until deselected + autotriggered near preselected limit.

(a) channel

i. air speed, altitude, G, vertical velocity - visual

ii. angle of attack - visual (selectable) plus audio (near limit)

(b) format

i. parametric linear, symbolic

ii. symbolic plus signal frequency

(c) location - selectable to HUD, HD fwd

(d) method - HUD projection, direct

(2) assessment - continuous/inherent in monitor

(a) channel - visual plus audio

(b) format

i. symbolic coincidence

ii. binary (off/on) audio

(c) location - same as for monitor

(d) method - same as for monitor

(3) correction - inherent in monitor -- NA

d. Route Space/Time (Mission Essential)

(1) monitor - continuous until deselected

(a) channel - visual

(b) format - graphic/map -- horizontal +(?) vertical fwd skeletonized

(c) location - HD central panel, HUD for time, V, hdg

(d) method - holographic for map, HUD projector

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - qualitative for velocity

- rate stoppage

- parametric for time/dis/hdg error

- symbolic for position difference (could do it all)

(c) location - as for monitor + vertical(?) HUD for parametrics, V rate stoppage, symbolic hdg

(d) method - holographic panel

(3) correction - coincident with assessment all categories same as for assessment

e. Environmental Hazard (e.g., Visibility, Hail, Icing, Turbulence) - Safety

(1) monitor - on call by category until deselected; selectably coincident with route monitor until deselected

(a) channel - visual

(b) format - symbolic and pictorial/ (terrain)

(c) location - HD central panel horizontal

(d) method - virtual

(2) assessment - during external control

(a) channel - as for monitor

(b) format - HUE

(c) location - as for monitor plus vertical

(d) method - as for monitor

(3) avoidance - inherent in/or coincident with monitor

(a) - (d) -- NA

f. Aircraft Limitations Criteria - Safety

(1) monitor - on call or autotrigger by preselected criteria; until deselected

(a) channel - visual

(b) format - graphic symbolic + alpha numeric; blink if autotriggered

(c) location - HD forward if selected; HUD if autotriggered

(d) method - direct view or projected

(2) assessment - coincident with monitor

(a) channel - visual

(b) format - graphic matching

(c) location - as for monitor

(d) method - as for monitor

(3) avoidance - same as for assessment

g. Cruise Energy Status - Mission Enhancing

(1) monitor - on call or autotriggered by preselected criteria; until deselected

(a) channel - visual

(b) format - parametric

(c) location - HD fwd

(d) method - direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - parametric comparison of desired and existing performance and results

(c) location - as for monitor

(d) as for monitor

(3) optimization/correction - coincident with assessment

(a) - (d) as for assessment

h. Aircraft Attitude Control - Aircraft Survival

(1) monitor - continuous

(a) channel - visual

(b) format - graphic symbolic + parametric

(c) location - HUD, HD vertical

(d) method - projected, direct

(2) assessment - during external control

(a) - (d) as for monitor

(3) correction - inherent in monitor

i. Traffic - (including enemy, sensor permitting) Safety/Mission Enhancing

(1) detection - automatic continuous when within safety criteria;

- until deselected for preselected criteria

- inherent with avoidance -- on call, coincident with route monitor

(a) channel - visual

(b) format - binary, blink plus graphic symbolic plus hue (for friend/foe)

(i) External Control - Mission Enhancement

(1) monitor - on call during control until deselected

i. channel - visual

ii. format - parametric, dial(C_n) + linear(V); graphic symbolic (C_n-EI)

iii. location - HUD, central panel horizontal and vertical - route space time display

iv. method - projected (HUD) - direct

(2) assessment - by coincident display of goal control path info

i. same as monitor

(3) malfunction - inherent in monitor (see subsystem)

(j) Threat - Aircraft Survival

(1) detection - autotriggered until criteria invalid or overridden

i. channel - redundant audio + visual

ii. format - color + relief symbolic audio signal frequency

iii. location - HUD, HD vertical and horizontal

iv. method - direct + indirect projection

(2) location - autotriggered coincident with detection, coincident with route display

   i. - iv. same as for detection

(3) evaluation/avoidance - autotriggered until overridden

   i. channel - visual

   ii. format - color + binary (flash) + graphic range effectiveness

   iii. location - same as "detection"

   iv. method - indirect + holographic

(m) Threat Countermeasures - Mission Enhancing

(1) monitor

i. channel - visual

ii. format - alpha binary + color

iii. location - HD subsystem panel

iv. method - direct

(2) CM system selection - same as monitor plus

ii. format - same

iii. location - HU + HD subsystem panel

iv. method - projection plus direct

(3) CM system employment - same as monitor plus

ii. format - alpha binary + blink - color

graphic?)

(2) location - on call coincident with route monitor

(a) channel - as for detection

(b) format - binary (direction indicator) plus graphic symbolic

(c) location - as for monitor

(d) method - as for monitor

(3) hazard assessment - automatic continuous within safety criteria until criteria invalid

(a) format - graphic symbolic

(b) correction - NA

(4) avoidance - automatic continuous within safety criteria until criteria invalid

(a) channel - as for monitor

(b) format - same as for monitor in general, but distinguishable (color/size)

(c) location - as for monitor

(d) method - as for monitor

j. Survival/Escape - Safety

(1) monitor - on call until deselected; autotriggered by safety and survival priority subsystem criteria

(a) channel - visual

(b) format - binary (goes to graphic symbolic)

(c) location - HUD + HD vertical

(d) method - projected plus direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - graphic symbolic/binary plus rate stoppage (matching)/size (qualitative)

(c) location - HUD + HD vertical

(d) method - as for monitor

(3) correction - NA

k. Maneuver Energy - Mission Enhancing

(1) monitor - on call until deselected

(a) channel - visual

(b) format - qualitative graphic

(c) location - HUD

(d) method - projection

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - coincidence/difference of graphics

(c) location - as for monitor

(d) method - as for monitor

(3) optimization - coincident with monitor

(a) - (d) as for assessment

1. Target - Mission Essential

(1) possible target detection - continuous with route

(a) channel - visual

(b) format - color + symbolic

(c) location - HUD + HD horizontal + vertical(?)

(d) method - holographic + indirect

(2) possible target location - continuous when derived, coincident with route

(a) - (d) same as for detection

(3) target ID - when derived until overridden, coincident with location

(a) channel - visual

(b) format - color, symbolic heightened relief

(c) location - same as detection

(d) method - same as detection

m. Threat Countermeasures - Mission Enhancing

(1) monitor

(a) channel - visual

(b) format - alpha binary + color

(c) location - HD subsystem panel

(d) method - direct

(2) CM system selection - same as monitor plus

(a) channel - visual

(b) format - same

(c) location - HU + HD subsystem panel

(d) method - projection plus direct

(3) CM system employment - same as monitor plus

(a) channel - visual

(b) format - alpha binary + blink + color

n. Subsystems - Aircraft Survival (Attitude Control and Power Systems)

(1) monitor

(a) channel - visual

(b) format - parametric linear

(c) location - HD fwd, subsystem display area

(d) method - direct

(2) assessment - as for monitor

(3) correction - NA

(4) malfunction

(a) channel - visual

(b) formt - binary blink + binary (display) alpha

(c) location - EMERG + HD fwd subsystem display area + HD horizontal preempt by alpha

(d) method - direct

(5) aircraft attitude control

(a) malfunction - trigger display of malfunction and monitor until correction

(b) assessment - inherent in display

(c) correction - by deactivation of display

(6) electric/hydraulic/pneumatic power system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) correction - coincident w/malfunction

(d) malfunction - trigger display and trigger monitor; trigger correction until deselected or corrected

o. Subsystems - Safety

(1) monitor (for those with degree-of-operation differentiation - those that fail/operate are not monitored)

(a) channel - visual

(b) format - alpha

(c) location - subsystems panel, HD fwd

(d) method - direct

(2) assessment (for those that monitor)

(a) channel - as for monitor

(b) format - parametric linear + graphic symbolic alongside

(c) location - as for monitor

(d) method - as for monitor

(3) correction - (for those that monitor) -- NA

(4) malfunction (autotriggers monitor)

(a) channel - as for monitor

(b) format - binary blink + binary alpha display

(c) location - EMERG + HD fwd subsystems display area + direct display horizontal preempts by alpha + HUD

(d) method - direct plus projection

(5) aircraft limitations criteria detection/ display - autotriggered until deselected

(6) damage/malfunction indicator system

(a) triggered, on call - until deselected

(7) engine system condition

(a) monitor - continuous until deselected; coincident w/performance correction

(b) assessment - coincident with monitor

(c) correction - coincident w/performance and correction

(8) fuel system

(a) monitor - on call until deselected and autotriggered by preselected criteria

(b) assessment - coincident w/monitor

(c) correction - coincident w/monitor

(d) malfunction/criticality - autotrigger; coincident autotrigger or monitor assessment and correction unless overridden

(9) cruise energy display

(a) malfunction - autotriggered until deselected

(10) internal environment system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) malfunction/criticality - autotrigger; coincident autotrigger of monitor and assessment until overridden

(11) traffic hazard system

(a) malfunction - autotrigger until deselected

(12) survival/escape system

(a) malfunction - autotrigger

(13) environmental hazard countermeasure system (anti-ice)

(a) malfunction - on call until deselected

p. Subsystems - Mission Essential

(1) monitor

(a) channel - visual (tactile-lighting

(b) format

i. comm - parametric digital

ii. navigation - parametric alpha-numeric

iii. carriage/release - binary, color, alpha

iv. weapon - binary, color, alpha

v. targeting - alpha

vi. threat - alpha

vii. lighting - position

(c) location

i. comm/navigation - HU console or lower panel

ii. carriage/release - HU

iii. weapon - HU

iv. targeting - HUD, horizontal, vertical fwd display areas

v. threat - subsystems panel, console, panel

vi. lighting - on control

(2) assessment - not required (inherent in monitor)

(a) channel - as for monitor

(b) format

i. comm - NR

ii. navigation - NR

iii. weapon - binary, color

iv. targeting - NR

v. threat - NR

vi. lighting - NR

(c) location - as for monitor

(d) method - direct

(3) correction - inherent -- NR

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary alpha

(c) location - EMERG + HD fwd subsystem display area + HUD

(d) method - direct + HUD projected

(5) communications system

(a) monitor - continuous

(b) assessment - inherent in monitor

(c) correction - inherent in monitor

(6) navigation system

(a) monitor - on call until deselected

(b) assessment - inherent in monitor

(c) correction - until corrected

(d) malfunction - autotriggered

(7) carriage/release system

(a) monitor - continuous

(b) malfunction - autotriggered

(8) weapon

(a) monitor - continuous

(b) assessment - coincident with monitor

(c) correction - coincident with monitor until corrected

(2) external environment sensor system - autotrigger

(3) control signal acceptance system - autotriggered

(4) aerodynamic parameter monitor system -

(a) malfunction - autotrigger

(b) correction - state shown after deselection/malfunction

(5) threat countermeasures - autotriggered

(6) security - autotrigger

(7) data storage

(a) monitor/operation (storage) - on call until deselected; by type of information; during storage

i. channel - visual

ii. format - binary alpha

iii. location - subsystem panel HD fwd

iv. method - direct

(b) malfunction - autotriggered

i. - iv. same as for monitor/ operation

(c) retrieval - on call for selectable threat and target information

i. - iv. same as for monitor/operation

(9) targeting system

(a) monitor - continuous (?)

(b) malfunction - autotrigger and on call (BIT) until deselected

(10) threat analysis system

(a) monitor - on call until deselected

(b) malfunction - autotriggered

(11) lighting system

(a) monitor - not required

(b) assessment - not required

(c) correction - not required

(12) maneuver energy optimization

(a) monitor - not required

(b) malfunction - autotriggered

q. Subsystems - Mission Enhancement

(1) For all except Data Storage

(a) malfunction

i. channel - visual

ii. format - binary blink plus binary alpha

iii. location - EMERG + HUD + subsystems panel HD fwd

iv. method - direct

(b) correction

i. - iv. as for malfunction

H. Phase: Weapon Delivery Area

1. Phase Required/Desired Information

a. Phase required/desired information

(1) Configuration

(2) Engine

(3) Damage/malfunction

(4) Aerodynamic performance

(5) Aircraft attitude control

(6) Environmental hazard

(7) Communications traffic

(8) Communications

(9) Route

(10) Subsystems

(11) Survival/escape

(12) Weapon

(13) Data storage

(14) Survival/escape

(15) Traffic

(16) Control signal

(17) Threat

(18) Target

(19) Environmental hazard (geographic)

(20) Fire control

(21) Full target

(22) Weapon control

(23) Increased data storage

2. Phase Required/Desired Action Displays -- Phase Timing and Priorities

a. Configuration - Safety

(1) monitor - until satisfactory

(a) channel - redundant tactile/visual

(b) format - redundant parametric/graphic (symbolic)

(c) location - HD on s bsystem display (fwd)

(d) method - direct view

(2) assessment - until matched -- all categories the same as monitor

(3) correction - by completion of display time

(a) channel - as for monitor

(b) format - as for monitor plus blink (?)

(c) location - as for monitor

(d) method - as for monitor

(4) malfunction - autotrigger monitor until corrected or overridden

(a) channel - as for monitor

(b) format - as for monitor; blink

(c) location - as for monitor plus HUD plus EMERG

(d) method - as for monitor

b. Engine Performance - Mission Essential

(1) monitor - on call until deselected

(a) channel - visual

(b) format - parametric digit/tape

(c) location - HD subsystem display (fwd)

(d) method - direct view

(2) assessment - coincident with monitor -- all categories the same as monitor

(3) correction - inherent in monitor -- NA

c. Aerodynamic Performance - Safety

(1) monitor - continuous for all but angle of attack; angle of attack -- when selected until deselected + autotriggered near preselected limit.

(a) channel

i. air speed, altitude, G, vertical velocity - visual

ii. angle of attack - visual (selectable) plus audio (near limit)

(b) format

i. parametric linear, symbolic

ii. symbolic plus signal frequency

(c) location - selectable to HUD, HD fwd

(d) method - HUD projection, direct

(2) assessment - continuous/inherent in monitor

(a) channel - visual plus audio

(b) format

i. symbolic coincidence

ii. binary (off/on) audio

(c) location - same as for monitor

(d) method - same as for monitor

(3) correction - inherent in monitor -- NA

d. Route Space/Time (Mission Essential)

(1) monitor - continuous until deselected

(a) channel - visual

(b) format - graphic/map -- horizontal +(?) vertical fwd skeletonized

(c) location - HD central panel, HUD for time, V, hdg

(d) method - holographic for map, HUD projector

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - qualitative for velocity

- rate stoppage

- parametric for time/dis/ hdg error

- symbolic for position difference (could do it all)

(c) location - as for monitor + vertical(?) HUD for parametrics, V rate stoppage, symbolic hdg

(d) method - holographic panel

(3) correction - coincident with assessment

e. Environmental Hazard (e.g., Visibility, Hail, Icing, Turbulence) - Safety

(1) monitor - on call by category until deselected; selectably coincident with route monitor until deselected

(a) channel - visual

(b) format - symbolic and pictorial/ (terrain)

(c) location - HD central panel horizontal

(d) method - virtual

(2) assessment - during external control

(a) channel - as for monitor

(b) format - HUE

(c) location - as for monitor plus vertical

(d) method - as for monitor

(3) avoidance - inherent in/or coincident with monitor

(a) - (d) -- NA

f. Aircraft Limitations Criteria - Safety

(1) monitor - on call or autotrigger by preselected criteria; until deselected

(a) channel - visual

(b) format - graphic symbolic + alpha numeric; blink if autotriggered

(c) location - HD forward if selected; HUD if autotriggered

(d) method - direct view or projected

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - parametric comparison of desired and existing performance and results

(c) location - as for monitor

(d) as for monitor

(3) optimization/correction - coincident with assessment

(a) - (d) as for assessment

h. Aircraft Attitude Control - Aircraft Survival

(1) monitor - continuous

(a) channel - visual

(b) format - graphic symbolic + parametric

(c) location - HUD, HD vertical

(d) method - projected, direct

(2) assessment - during external control

(a) - (d) as for monitor

(3) correction - inherent in monitor

i. Traffic - (including enemy, sensor permitting)

Safety/Mission Enhancing

(1) detection - automatic continuous when within safety criteria;

- until deselected for preselected criteria

- inherent with avoidance -- on call, coincident with route monitor

(a) channel - visual

(b) format - binary, blink plus graphic symbolic plus hue (for friend/foe)

(c) location - HUD, HD horizontal, THREAT

(d) method - direct plus direct (holographic?)

(2) location - on call coincident with route monitor

(a) channel - as for detection

(b) format - binary (direction indicator) plus graphic symbolic

(c) location - as for monitor

(d) method - as for monitor

(3) hazard assessment - automatic continuous within safety criteria until criteria invalid

   (a) format - graphic symbolic

   (b) correction - NA

(4) avoidance - automatic continuous within safety criteria until criteria invalid

   (a) channel - as for monitor

   (b) format - same as for monitor in general, but distinguishable (color/size)

   (c) location - as for monitor

   (d) method - as for monitor

j. Survival/Escape - Safety

(1) monitor - on call until deselected; autotriggered by safety and survival priority subsystem criteria

(a) channel - visual

(b) format - binary (goes to graphic symbolic)

(c) location - HUD + HD vertical

(d) method - projected plus direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - graphic symbolic/binary plus rate stoppage (matching)/size (qualitative)

(c) location - HUD + HD vertical

(d) method - as for monitor

(3) correction - NA

k. Maneuver Energy - Mission Enhancing

(1) monitor - on call until deselected

(a) channel - visual

(b) format - qualitative graphic

(c) location - HUD

(d) method - projection

(a) channel - as for monitor

(b) format - coincidence/difference of graphics

(c) location - as for monitor

(d) method - as for monitor

(3) optimization - coincident with monitor

(a) - (d) as for assessment

(i) External Control - Mission Enhancement

(1) monitor - on call during control until deselected

i. channel - visual

ii. format - parametric, dial (C_n) + linear (V); graphic symbolic (C_n-El

iii. location - HUD, central panel horizontal and vertical - route space time display

iv. method - projected (HUD) - direct

(2) assessment - by coincident display of goal control path info

i. same as monitor

(3) malfunction - inherent in monitor (see subsystem)

(j) Threat - Aircraft Survival

(1) detection - autotriggered until criteria invalid or overridden

i. channel - redundant audio + visual

ii. format - color + relief symbolic, audio signal frequency

iii. location - HUD, HD vertical and horizontal

iv. method - direct + indirect projection

(2) location - autotriggered coincident with detection, coincident with route display

i. - iv. same as for detection

(3) evaluation/avoidance - autotriggered until overridden

i. channel - visual

ii. format - color + binary (flash) + graphic range effectiveness

iii. location - same as "detection"

iv. method - indirect + holographic

(m) Threat Countermeasures - Mission Enhancing

(1) monitor

i. channel - visual

ii. format - alpha binary + color

iii. location - HD subsystem panel

iv. method - direct

(2) CM system selection - same as monitor plus

ii. format - same

iii. location - HU + HD subsystem panel

iv. method - projection plus direct

(3) CM system employment - same as monitor plus

ii. format - alpha binary + blink - color

1. Target - Mission Essential

(1) possible target detection - continuous coincident with route

(a) channel - visual

(b) format - color plus symbolic

(c) location - HUD + HD horizontal plus vertical

(d) method - holographic + indirect

(2) possible target location - continuous, coincident with route

(a) - (d) same as for detection

(3) target classification - when derived until overridden, coincident with location

(a) channel - visual

(b) format - color, symbolic, heightened relief

(4) target selection from clutter background - (noise, countermeasures, or multiple targets) - continuous coincident with location

(a) channel - visual

(b) format - intensity (suppression of non-selected targets)

(c) location - same as for detection

(d) method - same as for detection

(5) target designation - when designated until overridden coincident with location

(a) channel - visual

(b) format - symbolic and/or blink (e.g. circle tgt)

(c) location - same as detection

(d) method - same as detection

m. Weapon Readiness - Mission Essential

(1) monitor - on call plus simultaneous with weapon selection until overridden

(a) channel - visual

(b) format - binary (alpha/color)

(c) location - HU + HD fwd (wpn dedicated area)

(d) method - direct

(2) assessment - inherent in monitor

(3) correction - during corrective action/ inherent in monitor

n. Aircraft Launch Position/Time - Mission Essential

(1) selection - for selected systems by stored criteria; coincident with route and attitude; simultaneous with and conditional on target designation and weapon selection; until launch or de-selection of weapon

(a) channel - visual

(b) format - symbolic

(c) location - HUD, A/C route position time display

(d) method - indirect HUD, holographic

(2) deviation assessment - coincident and simultaneous with selection

(a) channel - visual

(b) format - symbolic coincidence + alpha (time)

(c) location - same as selection

(d) method - same as selection

(3) deviation correction - inherent in selection and deviation assessment

o. Weapon Selection - Mission Essential -- when selected until launch or deselection

(1) channel - visual

(2) format - binary alpha/color, on/off

(3) location - HU, (HUD?), HD fwd wpn dedicated area

(4) method - direct (HUD projection?)

p. Total Weapon System Readiness - Mission Essential

(1) detection - when weapon, weapon carriage & release, fire control and weapon (post launch) control systems are all ready, until launch

(a) channel - visual

(b) format - alpha + symbolic binary

(c) location - HU, HUD, HD wpn dedicated area

(d) method - direct + HUD projection

(2) assessment - by stored criteria; simultaneous with detection; until launch

(a) channel - visual

(b) format - color + symbolic blink

(c) location - same as detection

(d) method - same as detection

(3) correction - inherent in detection

(a) - (d) same as for assessment

q. Fire Control and Post Launch Weapon Control Systems Readiness - Mission Essential

(1) detection - on call until deselected; inherent in weapon system readiness detection/assessment

(a) channel - visual

(b) format - alpha binary + color

(c) location - HU + HD wpn dedicated area

(d) method - direct

(2) assessment - simultaneous with detection

(a) channel - visual

(b) format - binary blink + color

(c) location - same as detection

(d) method - same as detection

(3) correction - inherent in detection

(a) - (d) same as for assessment

r. Weapon Carriage & Release System Readiness - Mission Essential (same as for Fire Control, Weapon, Post Launch Control Systems)

(1) detection - on call until deselected; inherent in weapon system readiness detection/assessment)

(a) - (d) same as for fire control and post launch weapon control system readiness

(2) assessment - simultaneous with detection

(a) - (d) same as for detection

(3) correction - inherent in detection

(a) - (d) same as for monitor

s. Fire Control Solution (pre-launch) - Mission Enhancing

(1) presentation - on call until launch; coincident with aircraft launch/position/time selection

(a) channel - visual

(b) format - graphic symbolic

i. pictorial if imaging type sensor

ii. symbolic if non-imaging

(c) location - HUD, HD vertical by pre-emption for imaging

(d) method - HUD projection plus direct

(2) assessment - by stored criteria simultaneous with presentation

(a) channel - visual

(b) format - symbolic/image coincidence

(c) location - same as for presentation

(d) method - same as for pre tation

(3) correction - inherent in presentation; during application

t. Weapon Post Launch Control - Mission Essential

(1) presentation - upon launch (for selected weapons) until termination of requirement or impact, as selected

(a) channel - visual

(b) format - graphic

i. pictorial if imaging type

ii. symbolic if non-imaging

(c) location - HD vertical by preemption for pictorial + HUD for symbolic

(d) method - direct for HD, HUD projection

(2) assessment - inherent in presentation

(a) channel - same as presentation

(b) format - symbol/image coincidence

(c) location - same as presentation

(d) method - same as presentation

(3) correction - inherent in presentation; during application

(a) - (d) same as for assessment

u. Data Storage - Mission Enhancement

(1) operation (storage) - during collection until deselected; by type of information

(threat, target, fault isolation, delivery parameters, damage assessment)

(a) channel - visual

(b) format - alpha binary

(c) location - HD fwd subsystems display

(d) method - direct

v. Subsystems - Aircraft Survival (Attitude Control and Power Systems)

(1) monitor

(a) channel - visual

(b) format - parametric linear

(c) location - HD fwd, subsystem display area

(d) method - direct

(2) assessment - as for monitor

(3) correction - NA

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary (display) alpha

(c) location - EMERG + HD fwd subsystem display area + HD horizontal preempt by alpha

(d) method - direct

(5) aircraft attitude control

(a) malfunction - trigger display of malfunction and monitor until correction

(b) assessment - inherent in display

(c) correction - by deactivation of display

(6) electric/hydraulic/pneumatic power system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) correction - coincident w/malfunction

(d) malfunction - trigger display and trigger monitor; trigger correction until deselected or corrected

w. Subsystems - Safety

(1) monitor - (for those with degree-of-operation differentiation - those that fail/operate are not monitored)

(a) channel - as for monitor

(b) format - binary blink + binary alpha display

(c) location - EMERG + HD fwd subsystems display area + direct display horizontal preempts by alpha, + HUD

(d) method - direct

(2) assessment (for those that monitor)

(a) channel - as for monitor

(b) format - parametric linear + graphic symbolic alongside

(c) location - as for monit

(d) method - as for monitor

(3) correction - (for those that monitor) -- NA

(4) malfunction (autotriggers monitor)

(a) channel - as for monitor

(b) format - binary blink + binary alpha display

(c) location - EMERG + HD fwd subsystems display area + direct display horizontal preempts by alpha + HUD

(5) aircraft limitations criteria detection/display - autotriggered until deselected

(6) damage/malfunction indicator system

(a) triggered, on call - until deselected

(7) engine system condition

(a) monitor - continuous until deselected; coincident w/performance correction

(b) assessment - coincident with monitor

(c) correction - coincident w/performance and correction

(8) fuel system

(a) monitor - on call until deselected and autotriggered by preselected criteria

(b) assessment - coincident w/monitor

(c) correction - coincident w/monitor

(d) malfunction/criticality - autotrigger; coincident autotrigger or monitor assessment and correction unless overridden

(9) cruise energy display

(a) malfunction - autotriggered until deselected

(10) internal environment system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) malfunction/criticality - autotrigger; coincident autotrigger of monitor and assessment until overridden

(11) traffic hazard system

(a) malfunction - autotrigger until deselected

(12) survival/escape system

(a) malfunction - autotrigger

(13) environmental hazard countermeasure system (anti-ice)

(a) malfunction - on call until deselected

x. Subsystems - Mission Essential

(1) monitor

(a) channel - visual (tactile-lighting)

(b) format

i. comm - parametric digital

ii. navigation - parametric alpha-numeric

iii. carriage/release - binary, color, alpha

iv. weapon - binary, color, alpha

v. targeting - alpha

vi. threat - alpha

vii. lighting - position

(c) location

i. comm/navigation - HU console or lower panel

ii. carriage/release - HU

iii. weapon - HU

iv. targeting - HUD, horizontal, vertical fwd display areas

v. threat - subsystems panel, console, panel

vi. lighting - on control

(d) method - direct

(2) assessment - not required (inherent in monitor)

(a) channel - as for monitor

(b) format

i. comm - NR

ii. navigation - NR

iii. weapon

iv. targeting - NR

v. threat - NR

vi. lighting - NR

(c) location - as for monitor

(d) method - direct

(3) correction - inherent -- NR

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary alpha

(c) location - EMERG + HD fwd subsystem display area + HUD

(d) method - direct + HUD projected

(5) communications system

(a) monitor - continuous

(b) assessment - inherent in monitor

(c) correction - inherent in monitor

(6) navigation system

(a) monitor - on call until deselected

(b) assessment - inherent in monitor

(c) correction - until corrected

(d) malfunction - autotriggered

(7) carriage/release system

(a) monitor - continuous

(b) malfunction - autotriggered

(8) weapon

(a) monitor - continuous

(b) assessment - coincident with monitor

(c) correction - coincident with monitor until corrected

(9) targeting system

(a) monitor - continuous (?)

(b) malfunction - autotrigger and on call (BIT) until deselected

(10) threat analysis system

(a) monitor - on call until deselected

(b) malfunction - autotriggered

(11) lighting system

(a) monitor - not required

(b) assessment - not required

(c) correction - not required

(12) maneuver energy optimization

(a) monitor - not required

(b) malfunction - autotriggered

y. Subsystems - Mission Enhancement

(1) For all except Data Storage

(a) malfunction

i. channel - visual

ii. format - binary blink plus binary alpha

iii. location - EMERG + HUD + subsystems panel HD fwd

iv. method - direct

(b) correction

i. - iv. as for malfunction

(2) external environment sensor system - autotrigger

(3) control signal acceptance system - autotriggered

(4) aerodynamic parameter monitor system -

(a) malfunction - autotrigger

(b) correction - state shown after deselection/malfunction

(5) threat countermeasures - autotriggered

(6) security - autotrigger

(7) data storage

(a) monitor/operation (storage) - on call until deselected; by type of information; during storage

i. channel - visual

ii. format - binary alpha

iii. location - subsystem panel HD fwd

iv. method - direct

(b) malfunction - autotriggered

i. - iv. same as for monitor/operation

(c) retrieval - on call for selectable threat and target information

i. - iv. same as for monitor/operation

I. Phase: Target/Threat Area Retirement

1. Phase Required/Desired Information

a. Phase required/desired information

(1) Configuration

(2) Engine

(3) Damage/malfunction

(4) Aerodynamic performance

(5) Aircraft attitude control

(6) Environmental hazard

(7) Communications traffic

(8) Communications

(9) Route

(10) Subsystems

(11) Survival/escape

(12) Weapon

(13) Data storage

(14) Survival/escape

(15) Traffic

(16) Environmental hazard (geographic)

(17) Threat

2. **Phase Required/Desired Action Displays -- Phase Timing and Priorities**

   a. Configuration - Safety

      (1) monitor - until satisfactory

         (a) channel - redundant tactile/visual

         (b) format - redundant parametric/graphic (symbolic)

         (c) location - HD on subsystem display (fwd)

         (d) method - direct view

      (2) assessment - until matched -- all categories the same as monitor

      (3) correction - by completion of display time

         (a) channel - as for monitor

         (b) format - as for monitor plus blink (?)

         (c) location - as for monitor

         (d) method - as for monitor

      (4) malfunction - autotrigger monitor until corrected or overridden

         (a) channel - as for monitor

         (b) format - as for monitor; blink

         (c) location - as for monitor plus HUD plus EMERG

         (d) method - as for monitor

b. Engine Performance - Mission Essential

(1) monitor - on call until deselected

(a) channel - visual

(b) format - parametric digit/tape

(c) location - HD subsystem display (fwd)

(d) method - direct view

(2) assessment - coincident with monitor -- all categories the same as monitor

(3) correction - inherent in monitor -- NA

c. Aerodynamic Performance - Safety

(1) monitor - continuous for all but angle of attack; angle of attack -- when selected until deselected + autotriggerec near preselected limit.

(a) channel

i. air speed, altitude, G, vertical velocity - visual

ii. angle of attack - visual (selectable) plus audio (near limit)

(b) format

i. parametric linear, symbolic

ii. symbolic plus signal frequency

(c) location - selectable to HUD, HD fwd

(d) method - HUD projection, direct

(2) assessment - continuous/inherent in monitor

(a) channel - visual plus audio

(b) format

i. symbolic coincidence

ii. binary (off/on) audio

(c) location - same as for monitor

(d) method - same as for monitor

(3) correction - inherent in monitor -- NA

d. Route Space/Time (Mission Essential)

(1) monitor - continuous until deselected

(a) channel - visual

(b) format - graphic/map -- horizontal +(?) vertical fwd skeletonized

(c) location - HD central panel, HUD for time, V, hdg

(d) method - holographic for map, HUD projector

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - qualitative for velocity

- rate stoppage

- parametric for time/dis/ hdg error

- symbolic for position difference (could do it all)

(c) location - as for monitor + vertical(?)
HUD for parametrics, V rate stoppage,
symbolic hdg

(d) method - holographic panel

(3) correction - holographic panel

e. Environmental Hazard (e.g., Visibility, Hail, Icing, Turbulence) - Safety

(1) monitor - on call by category until deselected; selectably coincident with route monitor until deselected

(a) channel - visual

(b) format - symbolic and pictorial/ (terrain)

(c) location - HD central panel horizontal

(d) method - virtual

(2) assessment - during external control

(a) channel - as for monitor

(b) format - HUE

(c) location - as for monitor plus vertical

(d) method - as for monitor

(3) avoidance - inherent in/or coincident with monitor

(a) - (d) -- NA

f. Aircraft Limitations Criteria - Safety

(1) monitor - on call or autotrigger by preselected criteria; until deselected

(a) channel - visual

(b) format - graphic symbolic + alpha numeric; blink if autotriggered

(c) location - HD forward if selected; HUD if autotriggered

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - parametric comparison of desired and existing performance and results

(c) location - as for monitor

(d) as for monitor

(3) optimization/correction - coincident with assessment

(a) - (d) as for assessment

h. Aircraft Attitude Control - Aircraft Survival

(1) monitor - continuous

(a) channel - visual

(b) format - graphic symbolic + parametric

(c) location - HUD, HD vertical

(d) method - projected, direct

(2) assessment - during external control

(a) format - graphic symbolic

(b) correction - inherent in monitor

i. Traffic - (including enemy, sensor permitting)

Safety/Mission Enhancing

(1) detection - automatic continuous when within safety criteria;

- until deselected for preselected criteria

- inherent with avoidance -- on call, coincident with route monitor

(a) channel - visual

(b) format - binary, blink plus graphic symbolic plus hue (for friend/foe)

(c) location - HUD, HD horizontal, THREAT

(d) method - direct plus direct (holographic?)

(2) location - on call coincident with route monitor

(a) channel - as for detection

(b) format - binary (direction indicator) plus graphic symbolic

(c) location - as for monitor

(d) method - as for monitor

(3) hazard assessment - automatic continuous within safety criteria until criteria invalid

(a) format - graphic symbolic

(b) correction - NA

(4) avoidance - automatic continuous within safety criteria until criteria invalid

(a) channel - as for monitor

(b) format - same as for monitor in general, but distinguishable (color, size)

(c) location - as for monitor

(d) method - as for monitor

j. Survival/Escape - Safety

(1) monitor - on call until deselected; autotriggered by safety and survival priority subsystem critiera

(a) channel - visual

(b) format - binary (goes to graphic symbolic)

(c) location - HUD + HD vertical

(d) method - projected plus direct

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - graphic symbolic/binary plus rate stoppage (matching)/size (qualitative)

(c) location - HUD + HD vertical

(d) method - as for monitor

(3) correction - NA

k. Maneuver Energy - Mission Enhancing

(1) monitor - on call until deselected

(a) channel - visual

(b) format - qualitative graphic

(c) location - HUD

(d) method - projection

(2) assessment - coincident with monitor

(a) channel - as for monitor

(b) format - coincidence/difference of graphics

(c) location - as for monitor

(d) method - as for monitor

(3) optimization - coincident with monitor

(a) - (d) as for assessment

l. Target - Mission Essential

(1) possible target detection - continuous coincident with route

(a) channel - visual

(b) format - color plus symbolic

(c) location - HUD + HD horizontal plus vertical

(d) method - holographic + indirect

(2) possible target location - continuous, coincident with route

(a) - (d) same as for detection

(3) target classification - when derived until overridden, coincident with location

(a) channel - visual

(b) format - color, symbolic, heightened relief

m. External Control - Mission Enhancement

(1) monitor - on call during control until deselected

i. channel - visual

ii. format - parametric, dial(C_n) + linear(V); graphic symbolic (C_n-El)

iii. location - HUD, central panel horizontal and vertical - route space/time display

iv. method - projected (HUD) + direct

(2) assessment - by coincident display of goal control path info

i. same as monitor

(3) malfunction - inherent in monitor (see subsystem)

n. Threat - Aircraft Survival

(1) detection - autotriggered until criteria invalid or overridden

i. channel - redundant audio + visual

ii. format - color + relief symbolic, audio signal frequency

iii. location - HUD, HD vertical and horizontal

iv. method - direct + indirect projection

(2) location - autotriggered coincident with detection, coincident with route display

i. - iv. same as for detection

(3) evaluation/avoidance - autotriggered until overridden

i. channel - visual

ii. format - color + binary (flash) + graphic range effectiveness

iii. location - same as "detection"

iv. method - indirect + holographic

o. Threat Countermeasures - Mission Enhancing

(1) monitor

i. channel - visual

ii. format - alpha binary + color

iii. location - HD subsystem panel

iv. method - direct

(2) CM system selection - same as monitor plus

ii. format - same

iii. location - HU + HD subsystem panel

iv. method - projection plus direct

(3) CM system employment - same as monitor plus

ii. format - alpha binary + blink - color

p. Weapon Readiness - Mission Essential

(1) monitor - on call plus simultaneous with weapon selection until overridden

(a) channel - visual

(b) format - binary (alpha/color)

(c) location - HU + HD fwd (wpn dedicated area)

(d) method - direct

q. Weapon Selection - Mission Essential -- when selected until launch or deselection

(1) channel - visual

(2) format - binary alpha/color, on/off

(3) location - HU, (HUD?), HD fwd wpn dedicated area

r. Weapon Carriage & Release System Readiness - Mission Essential (same as for Fire Control, Weapon, Post Launch Control Systems)

(1) detection - on call until deselected; inherent in weapon system readiness detection/assessment)

(a) - (d) same as for fire control and post launch weapon control system readiness

(2) assessment - simultaneous with detection

(a) - (d) same as for detection

(3) correction - inherent in detection

(a) - (d) same as for monitor

s. Subsystems - Aircraft Survival (Attitude Control and Power Systems)

(1) monitor

(a) channel - visual

(b) format - parametric linear

(c) location - HD fwd, subsystem display area

(d) method - direct

(2) assessment - as for monitor

(3) correction - NA

(4) malfunction

(a) channel - visual

(b) format binary blink + binary (display) alpha

(c) location - EMERG + HD fwd subsystem display area + HD horizontal preempt by alpha

(d) method - direct

t. Data Storage - Mission Enhancement

(1) operation (storage) - during collection until deselected; by type of information (threat, target, fault isolation, delivery parameters, damage assessment)

(a) channel - visual

(b) format - alpha binary

(c) location - HD fwd subsystems display

(d) method - direct

(5) aircraft attitude control

(a) malfunction - trigger display of malfunction and monitor until correction

(b) assessment - inherent in display

(c) correction - by deactivation of display

(6) electric/hydraulic/pneumatic power system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) correction - coincident w/malfunction

(d) malfunction - trigger display and trigger monitor; trigger correction until deselected or corrected

u. Subsystems - Safety

(1) monitor (for those with degree-of-operation differentiation - those that fail/operate are not monitored)

(a) channel - visual

(b) format - alpha

(c) location - subsystems panel, HD fwd

(d) method - direct

(2) assessment (for those that monitor)

(a) channel - as for monitor

(b) format - parametric linear + graphic symbolic alongside

(c) location - as for monitor

(d) method - as for monitor

(3) correction (for those that monitor) -- NA

(4) malfunction (autotriggers monitor)

(a) channel - as for monitor

(b) format - binary blink + binary alpha display

(c) location - EMERG + HD fwd subsystems display area + direct display horizontal preempts by alpha + HUD

(d) method - direct

(5) aircraft limitations criteria detection/ display - autotriggered until deselected

(6) damage/malfunction indicator system

(a) triggered, on call - until deselected

(7) engine system condition

(a) monitor - continuous until deselected; coincident w/performance correction

(b) assessment - coincident with monitor

(c) correction - coincident w/performance and correction

(8) fuel system

(a) monitor - on call until deselected and autotriggered by preselected criteria

(b) assessment - coincident w/monitor

(c) correction - coincident w/monitor

(d) malfunction/criticality - autotrigger; coincident autotrigger of monitor assessment and correction unless overridden

(9) cruise energy display

(a) malfunction - autotriggered until deselected

(10) internal environment system

(a) monitor - continuous until deselected

(b) assessment - coincident w/monitor

(c) malfunction/criticality - autotrigger; coincident autotrigger of monitor and assessment until overridden

(11) traffic hazard system

(a) malfunction - autotrigger until deselected

(12) survival/escape system

(a) malfunction - autotrigger

(13) environmental hazard countermeasure system (anti-ice)

(a) malfunction - on call until deselected

v. Subsystems - Mission Essential

(1) monitor

(a) channel - visual (tactile-lighting)

(b) format

i. comm - parametric digital

ii. navigation - parametric alpha-numeric

iii. carriage/release - binary, color, alpha

iv. weapon - binary, color, alpha

v. targeting - alpha

vi. threat - alpha

vii. lighting - position

(c) location

i. comm/navigation - HU console or lower panel

ii. carriage/release - HU

iii. weapon - HU

iv. targeting - HUD, horizontal, vertical fwd display areas

v. threat - subsystems panel, console, panel

vi. lighting - on control

(d) method - direct

(2) assessment - not required (inherent in monitor)

(a) channel - as for monitor

(b) format

i. comm - NR

ii. navigation - NR

iii. weapon - binary, color

iv. targeting - NR

v. threat - NR

vi. lighting - NR

(c) location - as for monitor

(d) method - direct

(3) correction - inherent -- NR

(4) malfunction

(a) channel - visual

(b) format - binary blink + binary alpha

(c) location - EMERG + HD fwd subsystem display area + HUD

(d) method - direct + HUD projected

(5) communications system

(a) monitor - continuous

(b) assessment - inherent in monitor

(c) correction - inherent in monitor

(6) navigation system

(a) monitor - on call until deselected

(b) assessment - inherent in monitor

(c) correction - until corrected

(d) malfunction - autotriggered

(7) carriage/release system

(a) monitor - continuous

(b) malfunction - autotriggered

(8) weapon

(a) monitor - continuous

(b) assessment - coincident with monitor

(c) correction - coincident with monitor until corrected

(9) targeting system

(a) monitor - continuous (?)

(b) malfunction - autotrigger and on call (BIT) until deselected

(10) threat analysis system

(a) monitor - on call until deselected

(b) malfunction - autotriggered

(11) lighting system

(a) monitor - not required

(b) assessment - not required

(c) correction - not required

(12) maneuver energy optimization

(a) monitor - not required

(b) malfunction - autotriggered

w. Subsystems - Mission Enhancement

(1) For all except Data Storage

(a) malfunction

i. channel - visual

ii. format - binary blink plus binary alpha

iii. location - EMERG + HUD + subsystems panel HD fwd

iv. method - direct

(b) correction

i. - iv. - as for malfunction

(2) external environment sensor system - autotrigger

(3) control signal acceptance system - autotriggered

(4) aerodynamic parameter monitor system -

(a) malfunction - autotrigger

(b) correction - state shown after deselection/malfunction

(5) threat countermeasures - autotriggered

(6) security - autotrigger

(7) data storage

(a) monitor - when selected until deselected

i. channel - visual

ii. format - binary alpha

iii. location - subsystem panel HD fwd

iv. method - direct

(b) assessment/malfunction - on call until deselected

I am Commander Lee, Commanding Officer, VA-147. It pleases me to be here - it's not often aviators get a say in what goes in to an airplane. I will talk about the single place attack mission.

1. SLIDE. This is what we have used for many years to fly airplanes - completely heads down. Not comfortable.

2. SLIDE. The heads up display has come about in the last few years and for old hands is hard to get used to.

3. SLIDE. The big question is how much information should and can be displayed on the HUD and be useful to the pilot. In these last two slides the attempt has been to show what the pilot sees during a night catapult launch. It's very difficult to show on a screen.

The attack mission can be divided into three distinct phases. - Take off/landing, Enroute and the attack phase. The combination of heads up and heads down displays must be harmonized to accomplish all phases effectively and safely. After talking to many attack pilots I have come up with the idea of the heads up display with all info to fly the aircraft during any pahse but selectable for each individual phase. Instead of all other information being displayed totally heads down, we should have a multi display unit just below the HUD that can be seen at the same head position. This unit could display any desired information at pilot request from aircraft system health to radar to EW.

4. SLIDE. Enroute this display could be programmed to display navigation and enemy order of battle as predicted prior to flight. The enroute HUD should show, heading, speed, time, attitude velocity vector and wind. The display lines must be thin and the presentation unclutterred. Information should be selectable in groups for complete navigation and system management.

5. SLIDE. Radar and projected maps are necessary for enroute navigation. Each scale of radar should be matched by a map scale for both normal terrain and radar charts. Computer generated radar should be capable of being displayed on the multi display unit and should compare to the radar chart presentation.

6. SLIDE. EW gear must be displayed in a useable method. Present gear shows much too much information in a high threat environment. The single place airplane must have a more useful EW threat display so that the pilot can fly the airplane and counter the highest threat. The present system reminds one of an excited pinball machine.

7. SLIDE. In the close air support role the overriding proglem is that everyone is on a different frequency band and the pilot cannot talk directly to the man needing air cover. With multiple radios - monitoring frequencies and responding to calls on different frequencies is an almost impossible task in a single place airplane.

8. SLIDE. The attack mission is primarily to get bombs on target - hitting the target the first time instead of having to make the same trip more than once. 9. SLIDE.

10. SLIDE. Pinpoint accuracy is what is required and it has been proven that aircraft today can hit as well as the pilot can acquire and track the target.

11. SLIDE. CEPs of less than 40 feet are fairly common. The only way to improve over this is with smart weapons. Displays for target acquisition by IR, laser, low light T. V., ect., must be included in displays of the future.

Many missions in today's senarios call for off boresite weapons delivery. 12. SLIDE.

In many missions the pilot would have one pass to attack the target and if it did not appear directly in front of the airplane upon acquisition, the mission could very well be unsuccessful.

14. SLIDE. We must have an off-boresite aiming capability incorporated into the HUD. The attack mode HUD should cover at least the forward windscreen for maneuvering and weapons system displays. All weapons information should be displayed so that it is not necessary to look inside the cockpit. Weapons parameters should be programmable with individual FRAG patterns included. The attack phase presentations should be selectable by the pilot for any light intensity desired; - a big problem presently is that night lighting is too bright and not nearly selectable enough.

The attack phase should also include mission completion information. At the pre-programmed fuel a bingo profile should be displayed giving altitude and airspeed taking into account winds.

14. SLIDE. The landing phase presentations should be much like take-off.

15. SLIDE. The biggest concern is instrument flight.

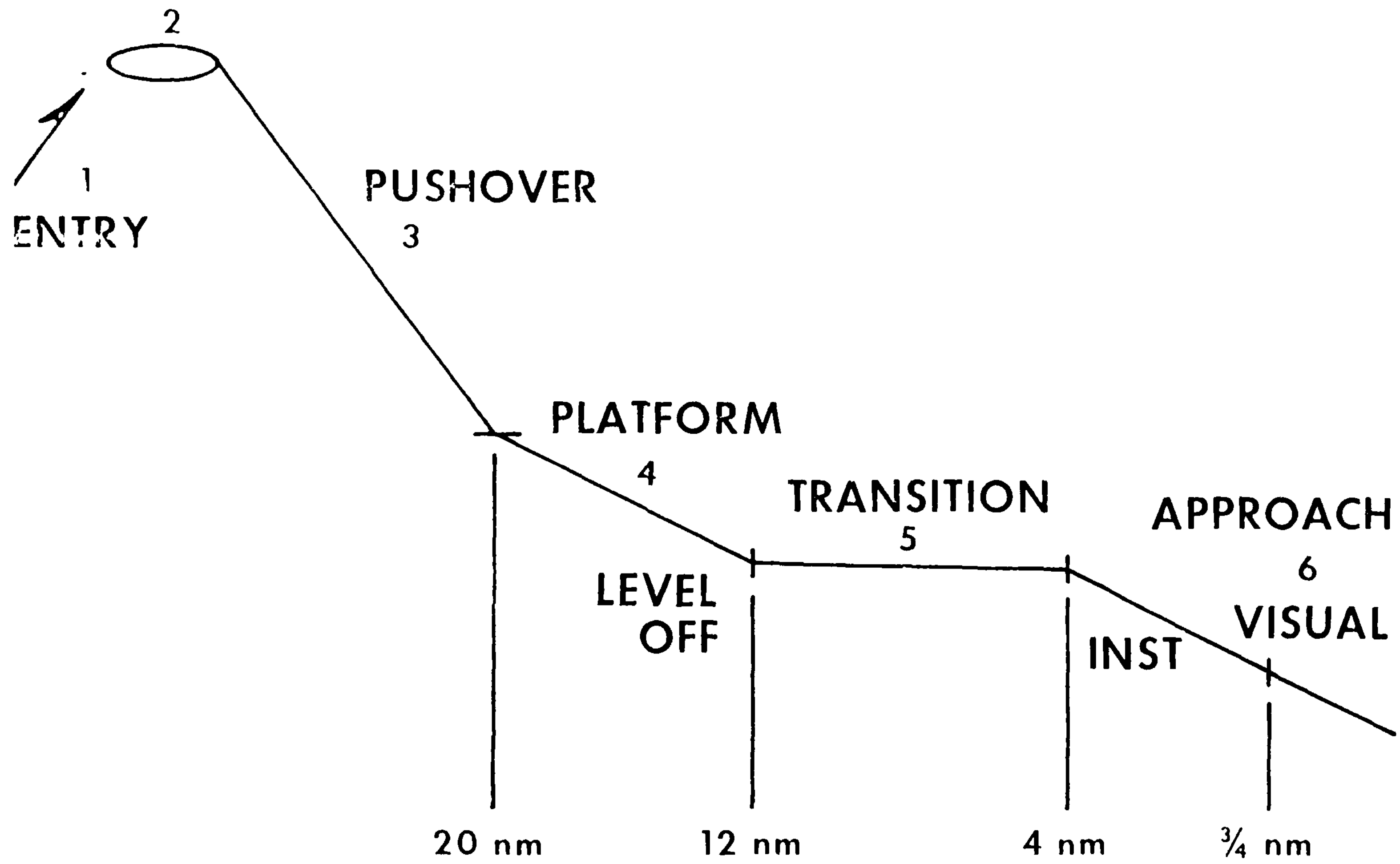
16. SLIDE. Large attitude lines with critical airspeed indication that shows trend. The ability for lining the airplane up with the ship is critical.

17. SLIDE. The present airplanes have combinations of things of the future and/or the distant past. Future airplanes should be built with the aviator and specific mission more in mind and the cockpit should be oriented along the lines of mission performance instead of just satisfying a requirement for displays.

DISPLAY OPERATIONAL REQUIREMENTS

LCDR MITCHELL

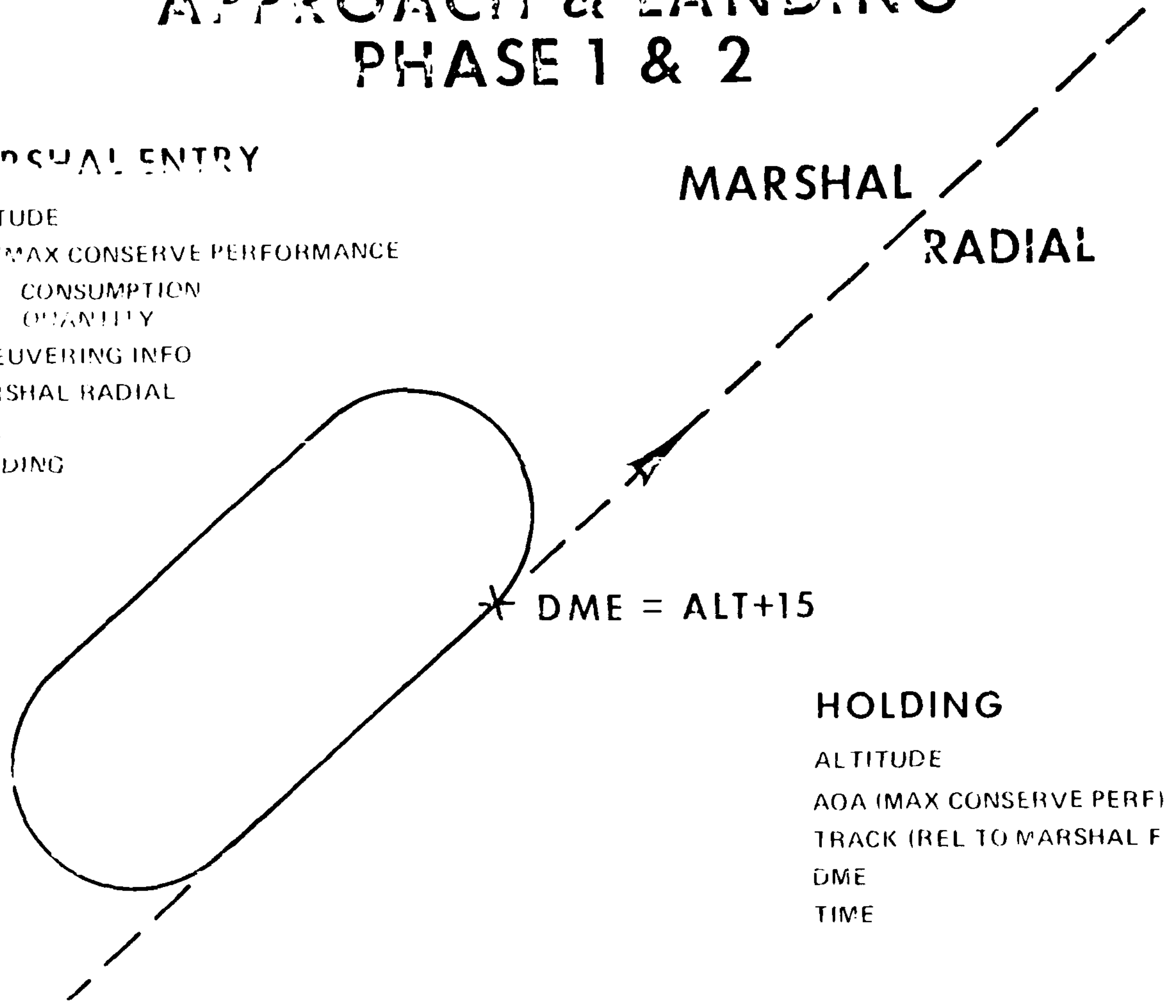
APPROACH & LANDING



APPROACH & LANDING
PHASE 1 & 2

MARSHAL ENTRY

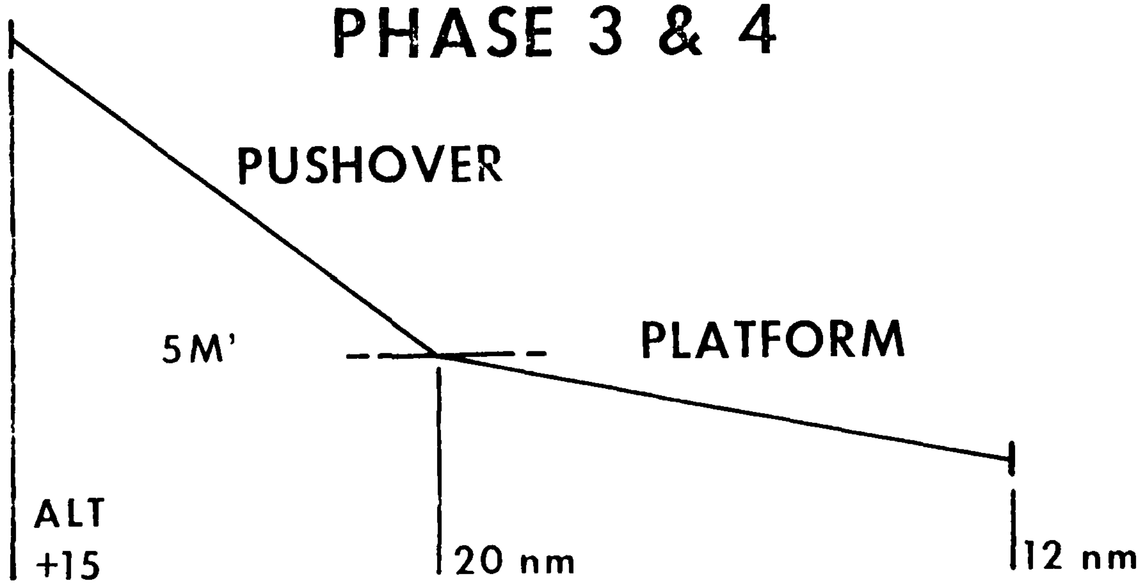
ALTITUDE
AOA (MAX CONSERVE PERFORMANCE
FUEL CONSUMPTION
QUANTITY
MANEUVERING INFO
MARSHAL RADIAL
DME
HEADING
TIME



HOLDING

ALTITUDE
AOA (MAX CONSERVE PERF)
TRACK (REL TO MARSHAL FIX)
DME
TIME

APPROACH & LANDING
PHASE 3 & 4



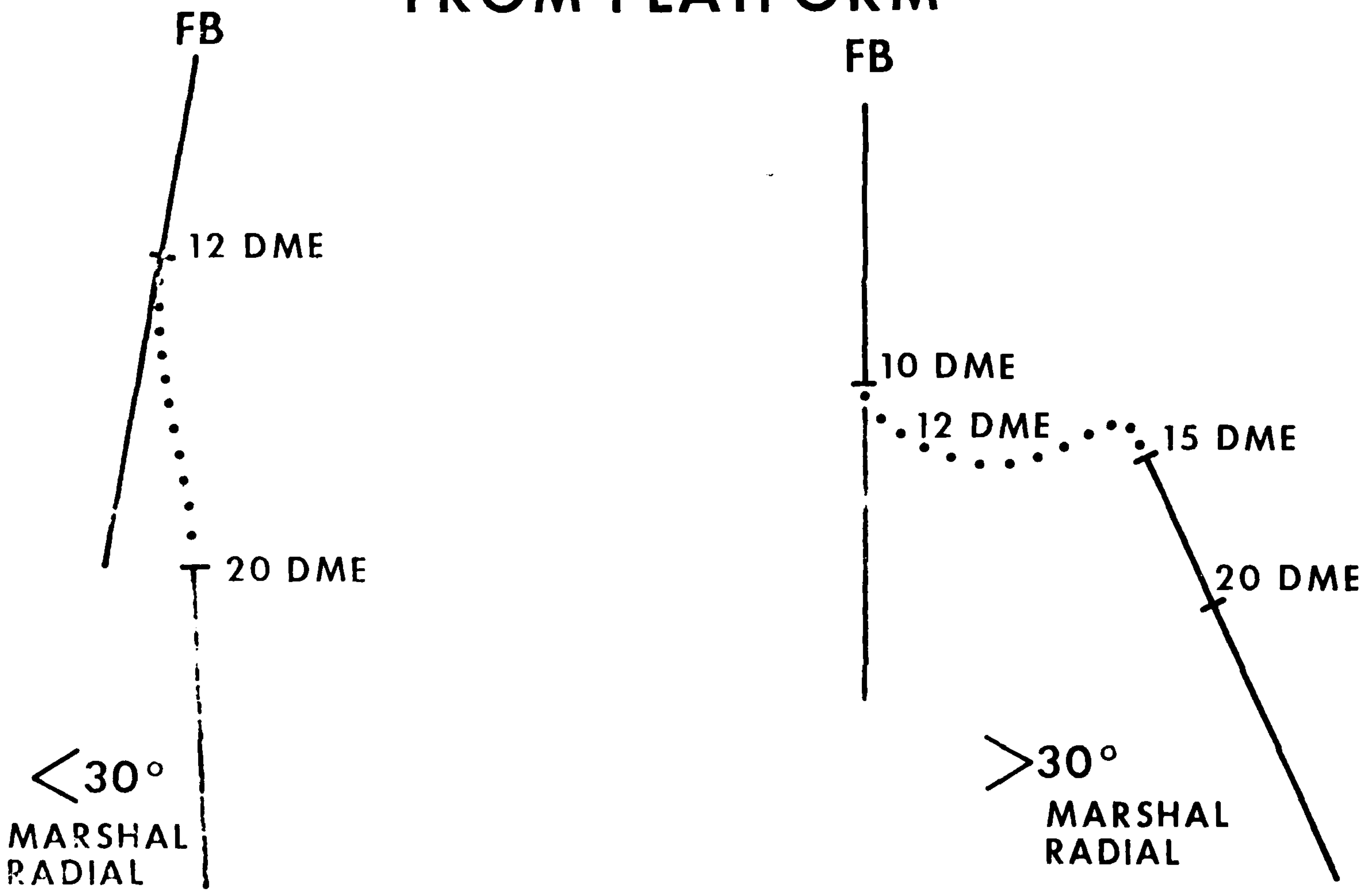
PUSHOVER

ALTITUDE
TIME
AIRSPEED
DME
HEADING
VERTICAL SPEED
FINAL BEARING

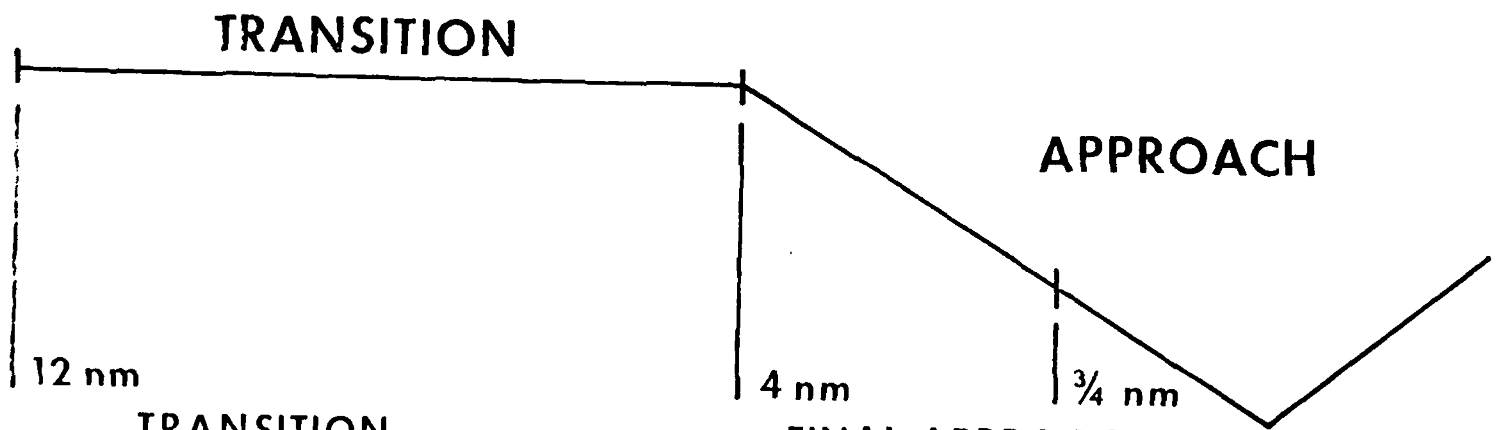
PLATFORM

ALTITUDE
DME
VERTICAL SPEED
AIRSPEED
HEADING
TURN TO FINAL BEARING

CORRECTIONS TO FINAL BEARING FROM PLATFORM



APPROACH & LANDING
PHASE 5&6



TRANSITION

ALTITUDE
AIRSPEED/AOA
POWER SETTING
CONFIGURATION
HEADING
FINAL BEARING
SUB-SYSTEM STATUS
APC
ACLS
FUEL STATE

FINAL APPROACH

AZMTH/ELEV
AOA
VSI
FUEL FLOW
ALT/DME
WAVE-OFF

AZMTH
ELEV
AOA

WAVE-OFF

ATTITUDE
AOA
ALTITUDE

F-18 CREW STATION DESIGN-UPDATE

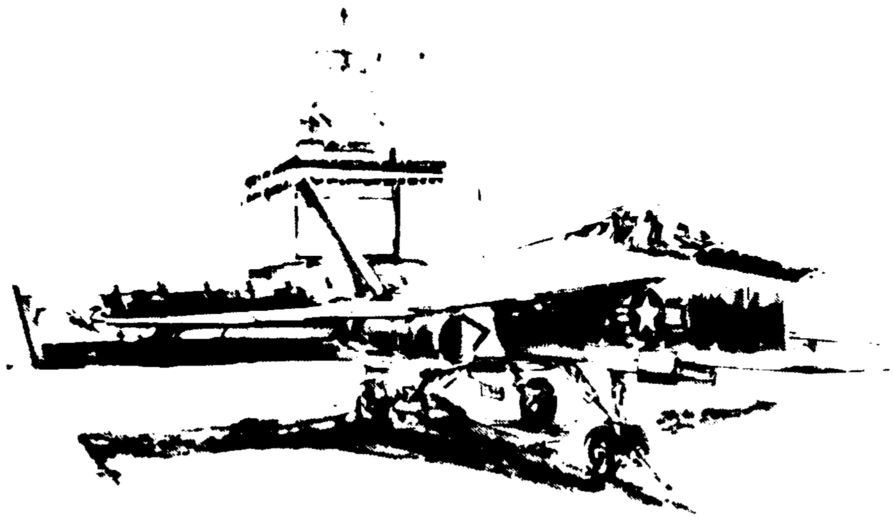
Eugene C. Adam

McDonnell Douglas Corporation

St. Louis, Missouri

The F-18 Crew Station design represents a considerable step forward in the application of computer controlled CRT's and integrated controls to the reduction of pilot workload and enhancement of mission success. The requirement in the F-18 crew station design was to essentially provide the capability contained in both the F-4 and A-7 weapon systems, make it operable by one pilot, and provide an order of magnitude increase in cockpit mission reliability.

To put this requirement in perspective the F-18 cockpit is 40% smaller in terms of usable area than any of its contemporaries. This area constraint necessitated maximum integration of the weapon system controls and displays. The following charts describe the rationale leading up to the configuration and present a few examples of the one-man-operability features in the F-18 and how they would be used by the pilot. The crew station design is being generated and validated by a vigorous process of analysis, USN aircrew systems advisory panel evaluations and simulation.

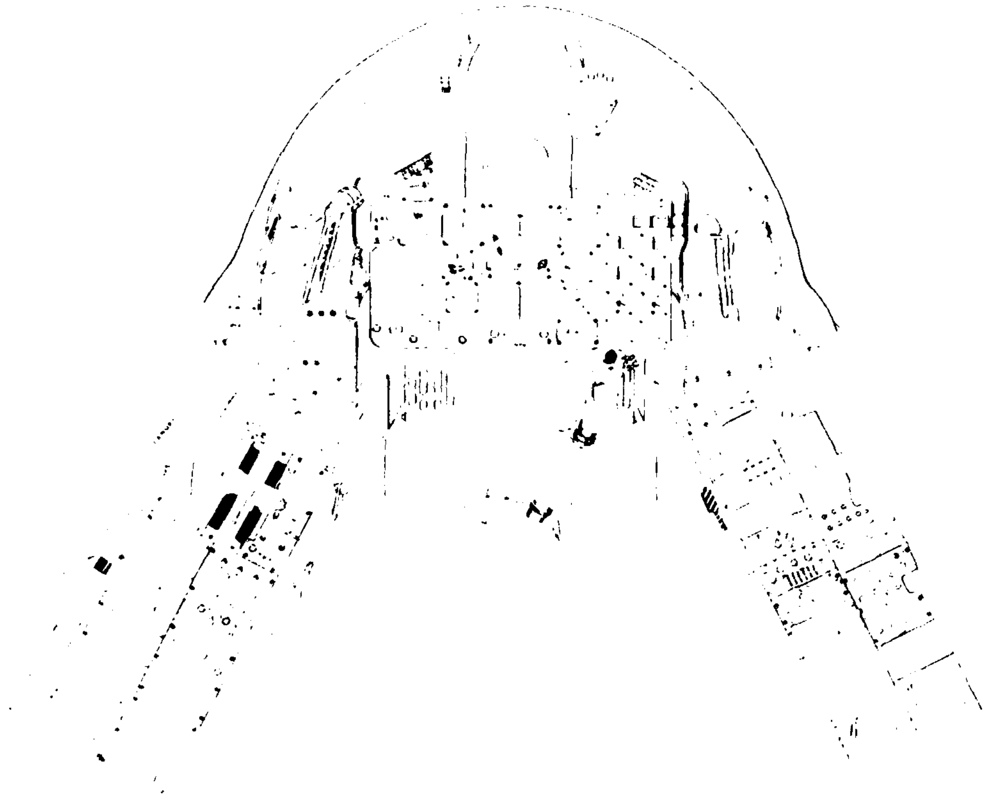


F/18

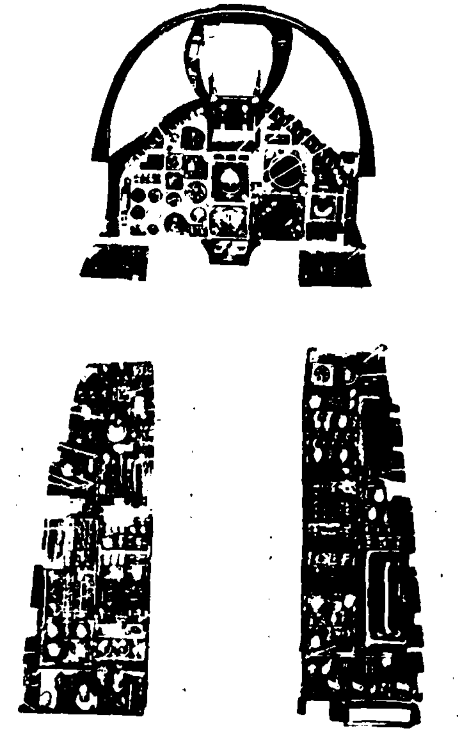
U.S. NAVY/U.S.M.C.
FIGHTER ATTACK

F-18 COCKPIT REQUIREMENTS

1. PROVIDE COMBINED, EQUIVALENT C&D FUNCTIONS AS CONTAINED IN THE F-4J AND A-7



F4-J

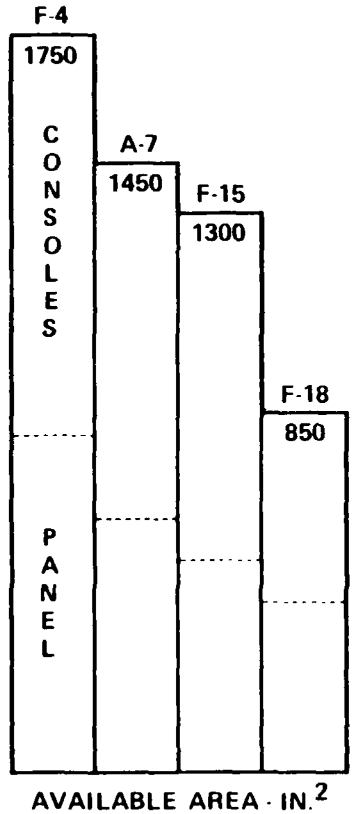


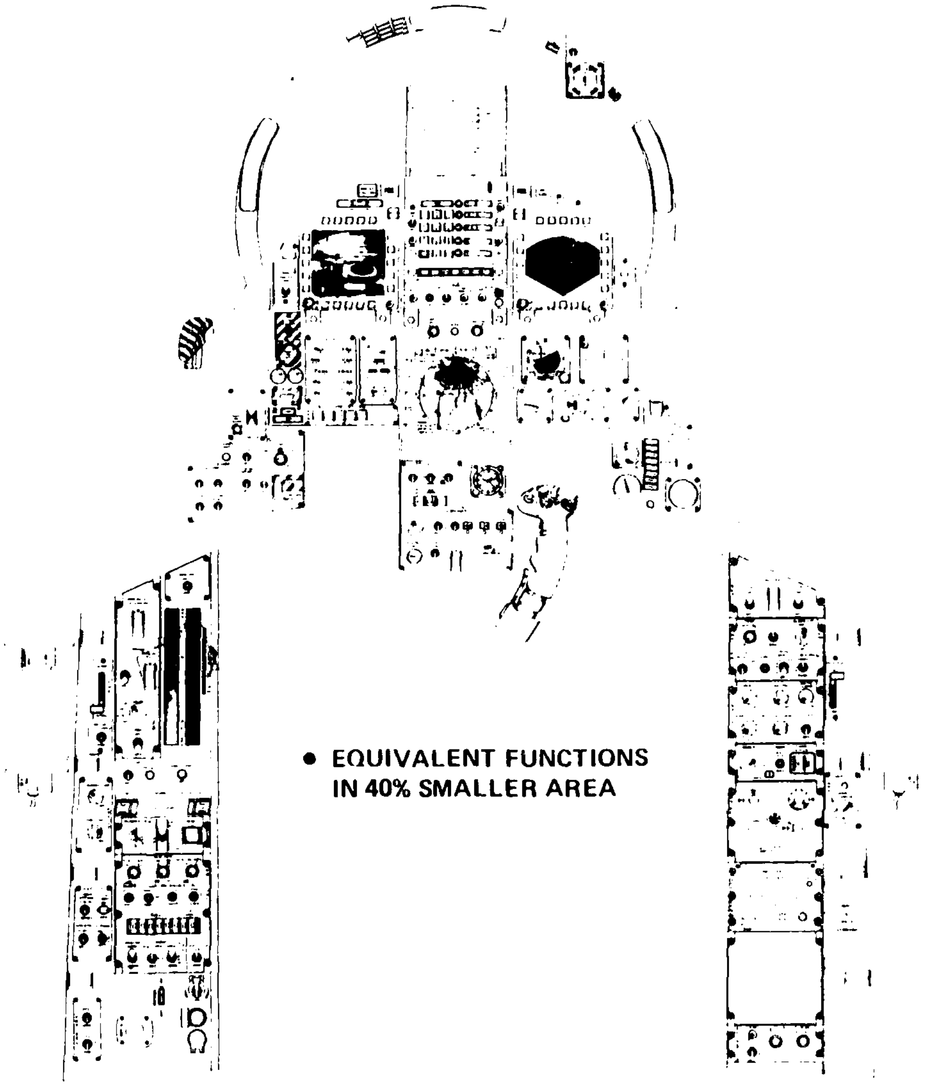
A7-E

2. PROVIDE ONE-MAN OPERABILITY FOR THE F-18 STRIKE FIGHTER MISSIONS

3. IMPROVE COCKPIT RELIABILITY, MAINTAINABILITY AND PILOT EFFECTIVENESS WITHIN THE DESIGN-TO-COST CONSTRAINTS

F-18 vs CONTEMPORARY COCKPIT AREAS

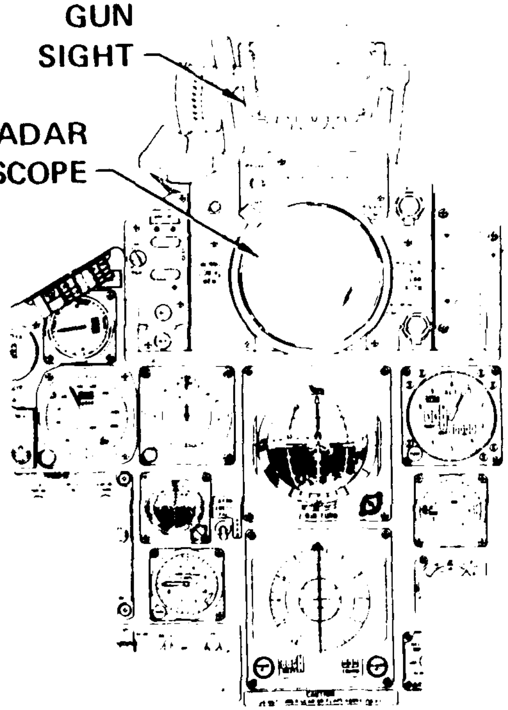




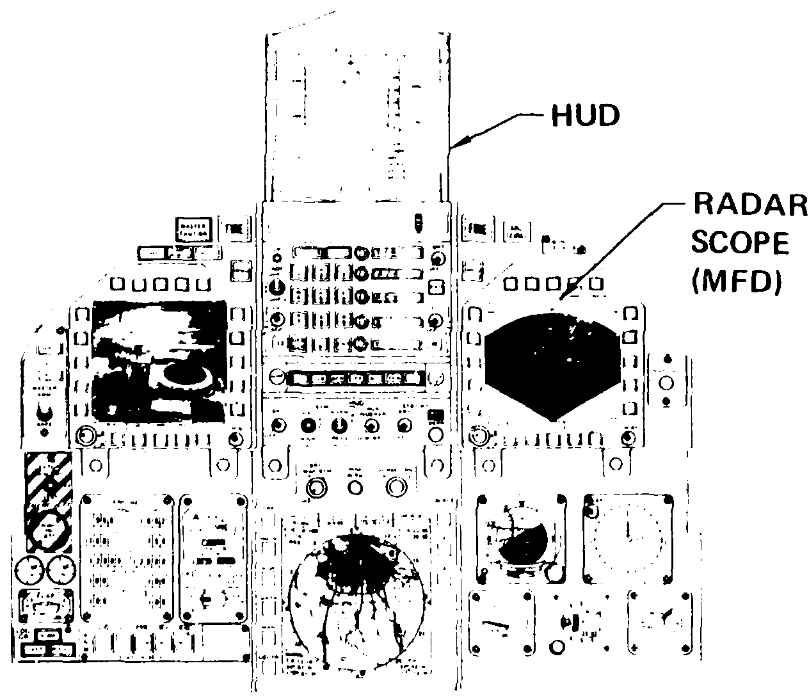
- EQUIVALENT FUNCTIONS IN 40% SMALLER AREA

HEAD-UP DISPLAY (HUD) AND MULTI FUNCTION DISPLAY (MFD)

F-4 SEPARATE DISPLAYS



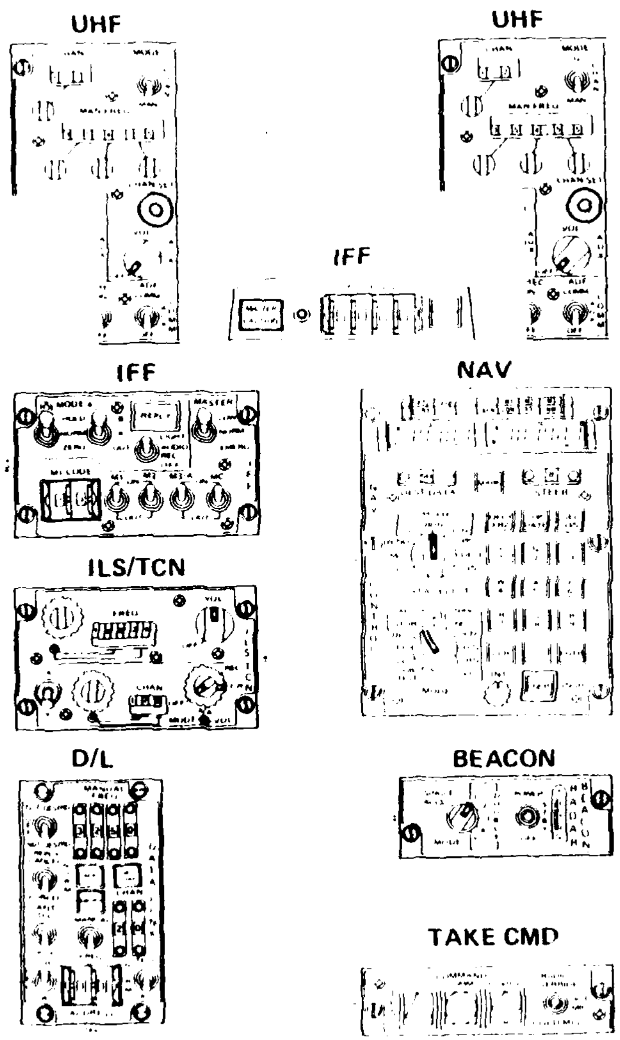
F-18 (A-7, F-14) INTEGRATED DISPLAYS



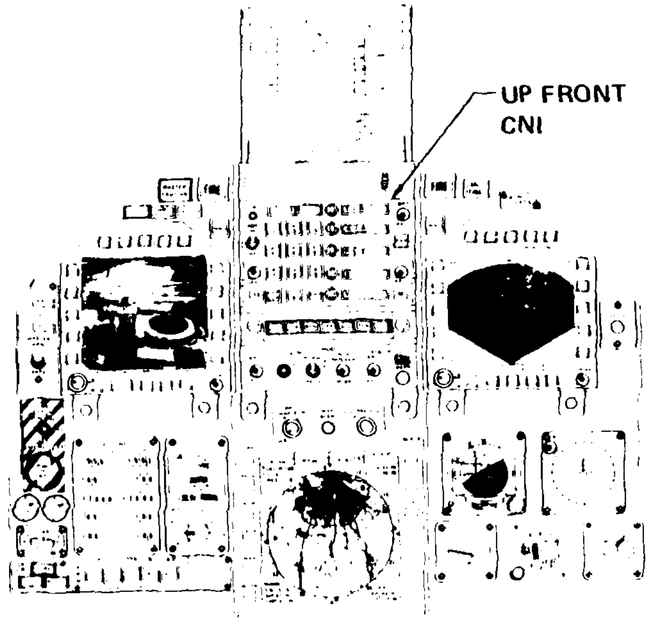
GP75 0500 203

CNI FUNCTIONS
VIA UP-FRONT CONTROL

SEPARATE CONTROLS



F-18 INTEGRATED CONTROLS



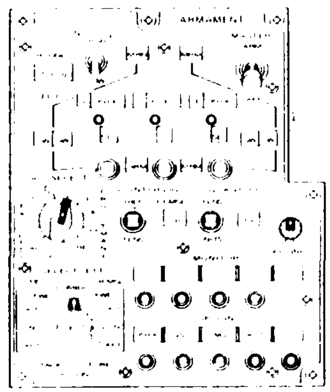
		SEPARATE	INTEGRATED
WEIGHT	(LB)	30	7
AREA	(IN.^{2})	150	30
RELIABILITY	(HRS)	1000	3000
MAINTAINABILITY	(MMH/FH)	0.017	0.002
NONRECURRING		1.0	0.5
RECURRING		1.0	0.5

GP75 0500 20

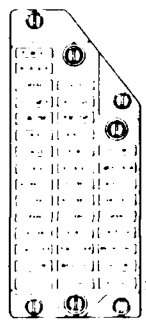
MASTER MONITOR DISPLAY (MMD)

SEPARATE CONTROLS AND DISPLAYS

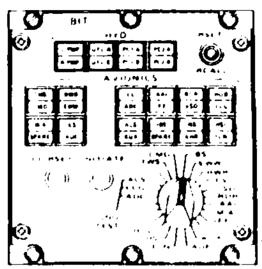
ARMAMENT



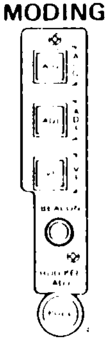
CAUTION



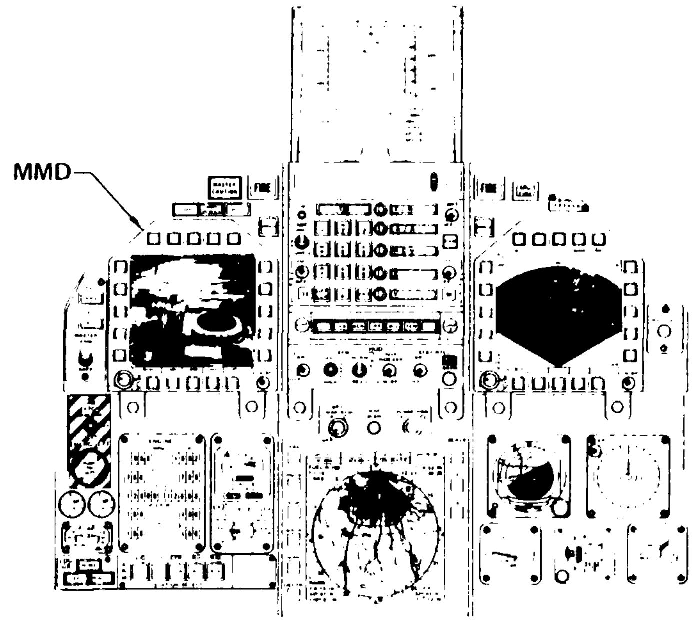
BIT



MODING



F-18 INTEGRATED CONTROLS AND DISPLAYS



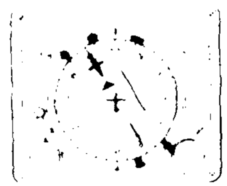
		SEPARATE	INTEGRATED
WEIGHT	(LB)	24	25
AREA	($IN.^2$)	270	40
RELIABILITY	(HRS)	800	2000
MAINTAINABILITY	(MMH/FH)	0.04	0.02
NONRECURRING		1.0	0.9
RECURRING		1.0	1.0

GP75 0500 205

25 AUG 1975

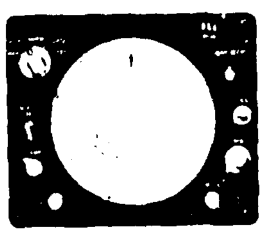
HSI/EW AND MAP FUNCTIONS
ON A HORIZONTAL SITUATION DISPLAY (HSD)

SEPARATE DISPLAYS



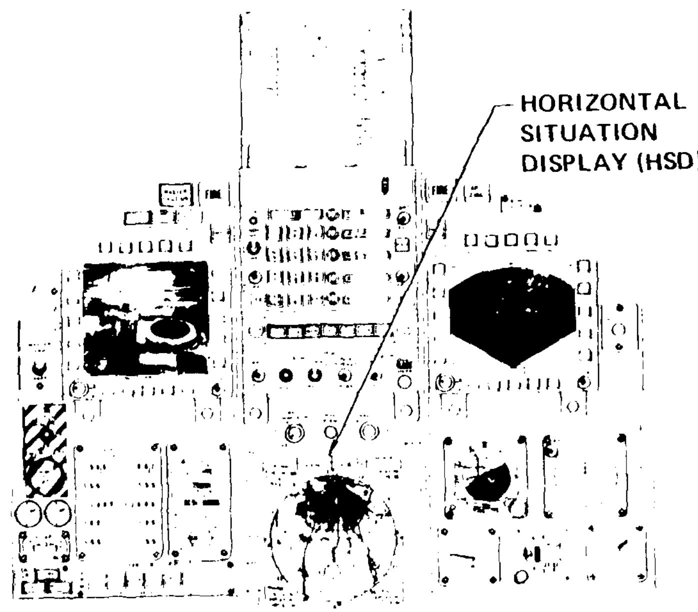
HSI

EW



MAP

F-18 INTEGRATED DISPLAY

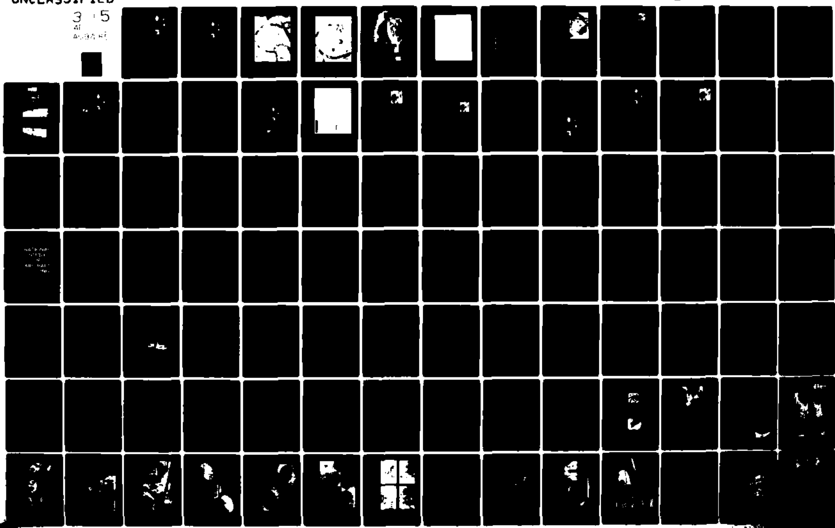


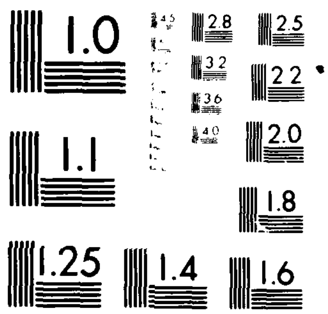
		SEPARATE	INTEGRATED
WEIGHT	(LB)	58	53
AREA	($IN.^2$)	100	55
RELIABILITY	(HR)	300	500
MAINTAINABILITY	MMH/FH	0.05	0.025
NONRECURRING		1.0	1.2
RECURRING		1.0	1.5

AD-A097 285 NAVAL AIR TEST CENTER PATUXENT RIVER MD F/G 5/8
ADVANCED AIRCREW DISPLAY SYMPOSIUM (3RD), 19-20 MAY.(U)
1976

UNCLASSIFIED NL

3 of 5

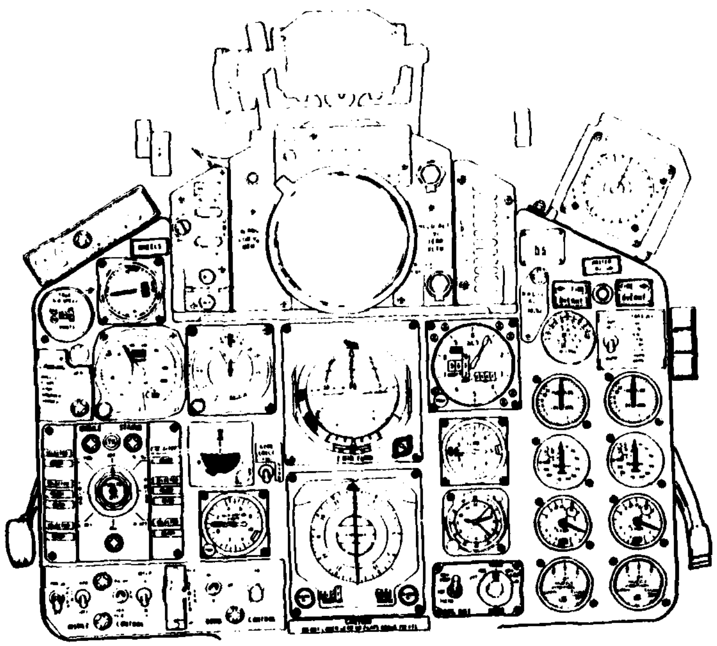




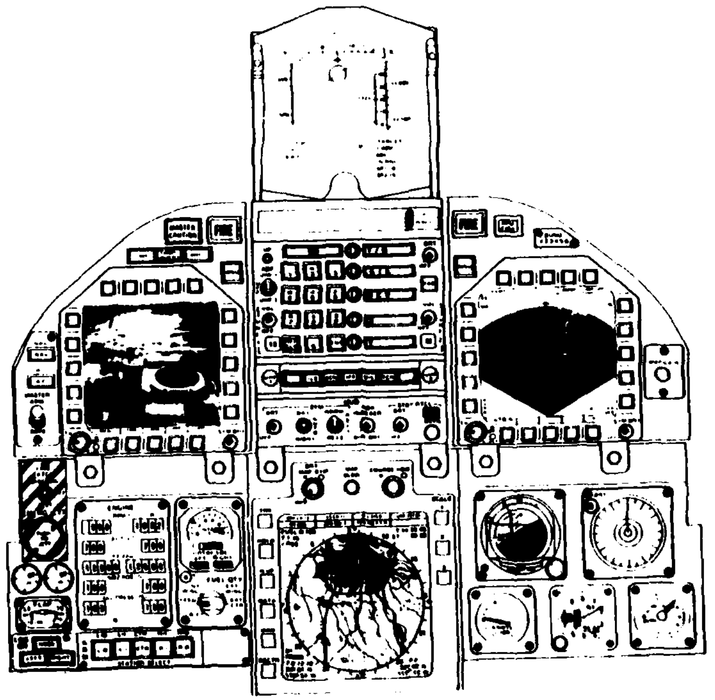
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ENGINE INSTRUMENTS

F-4

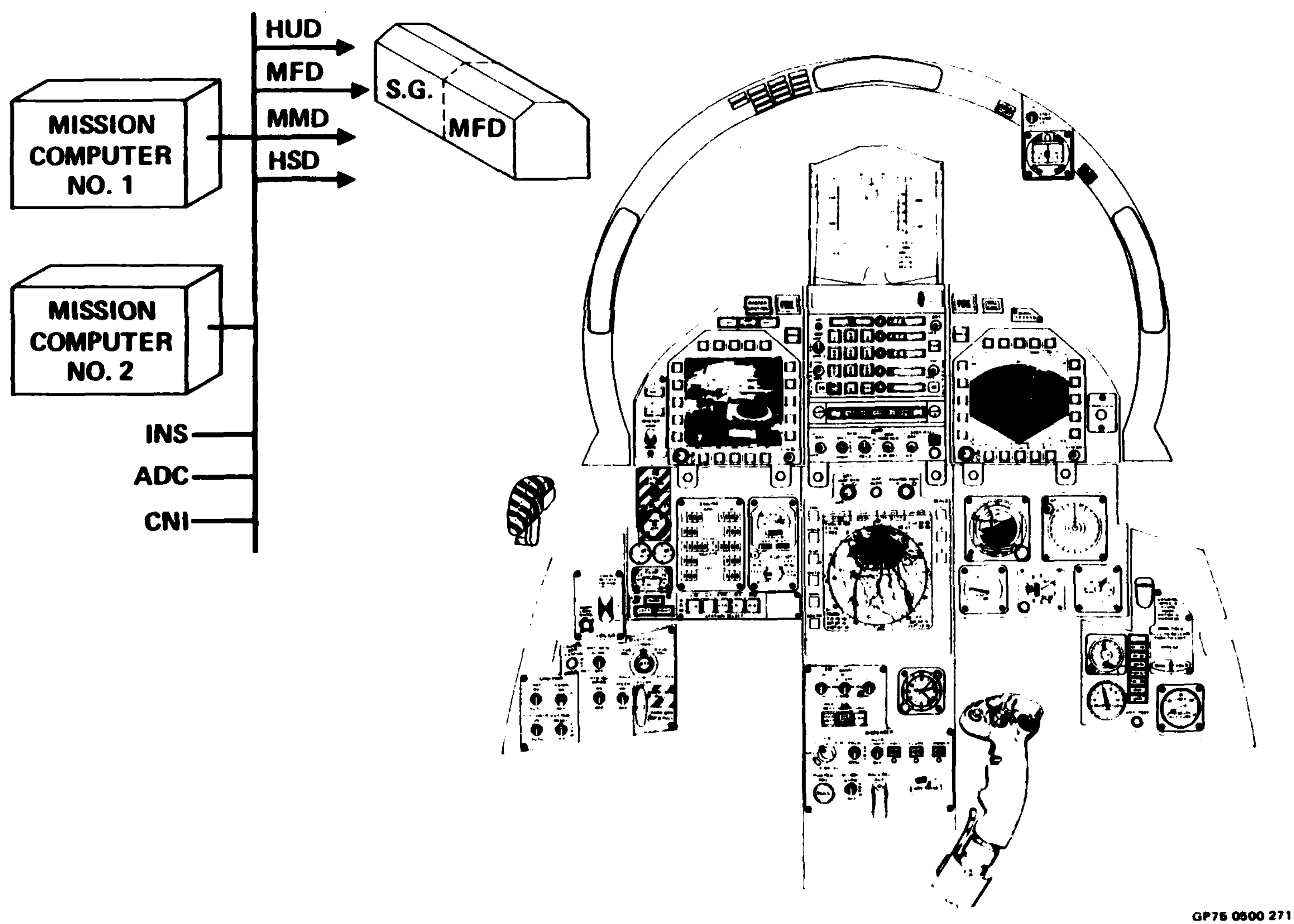


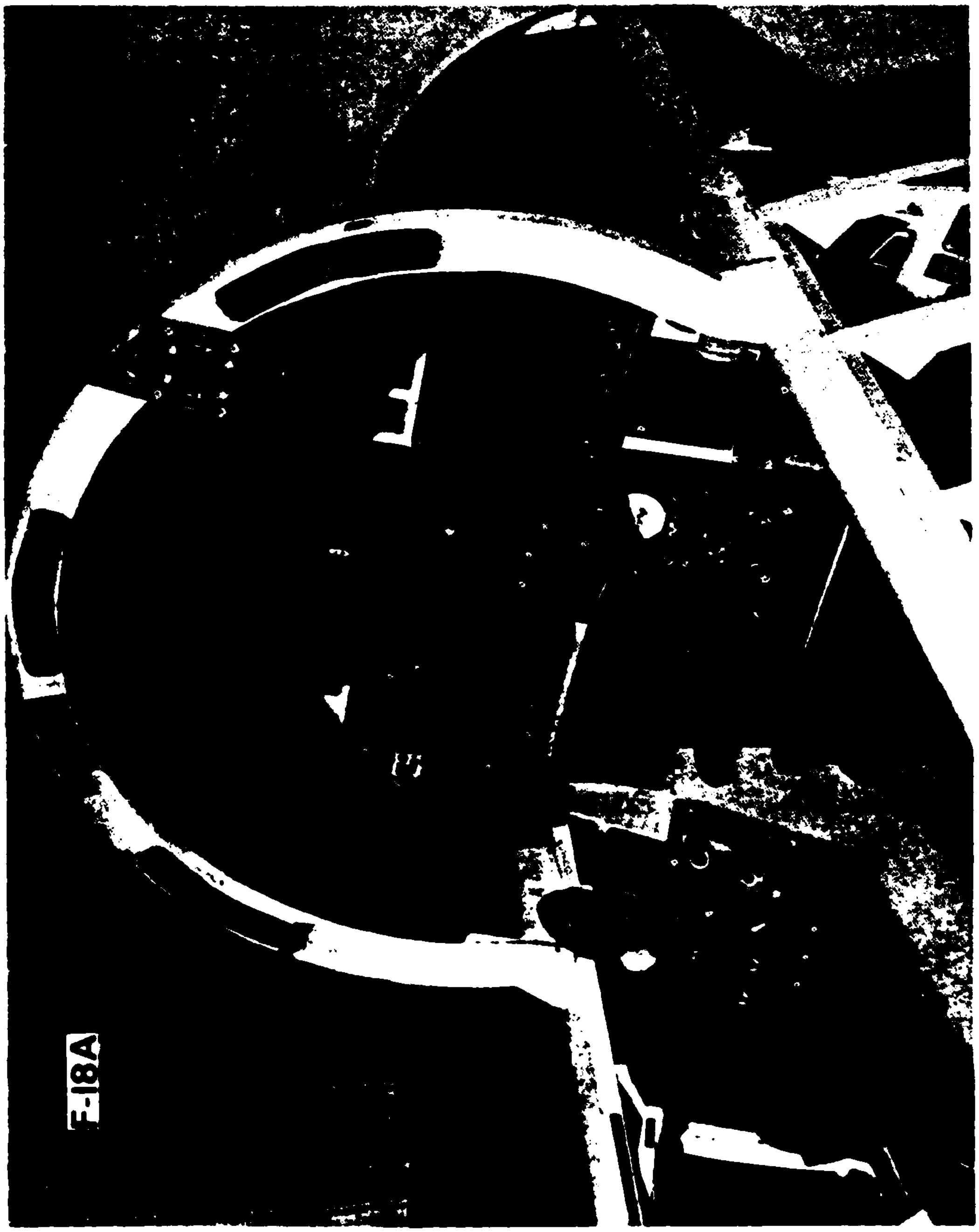
F-18

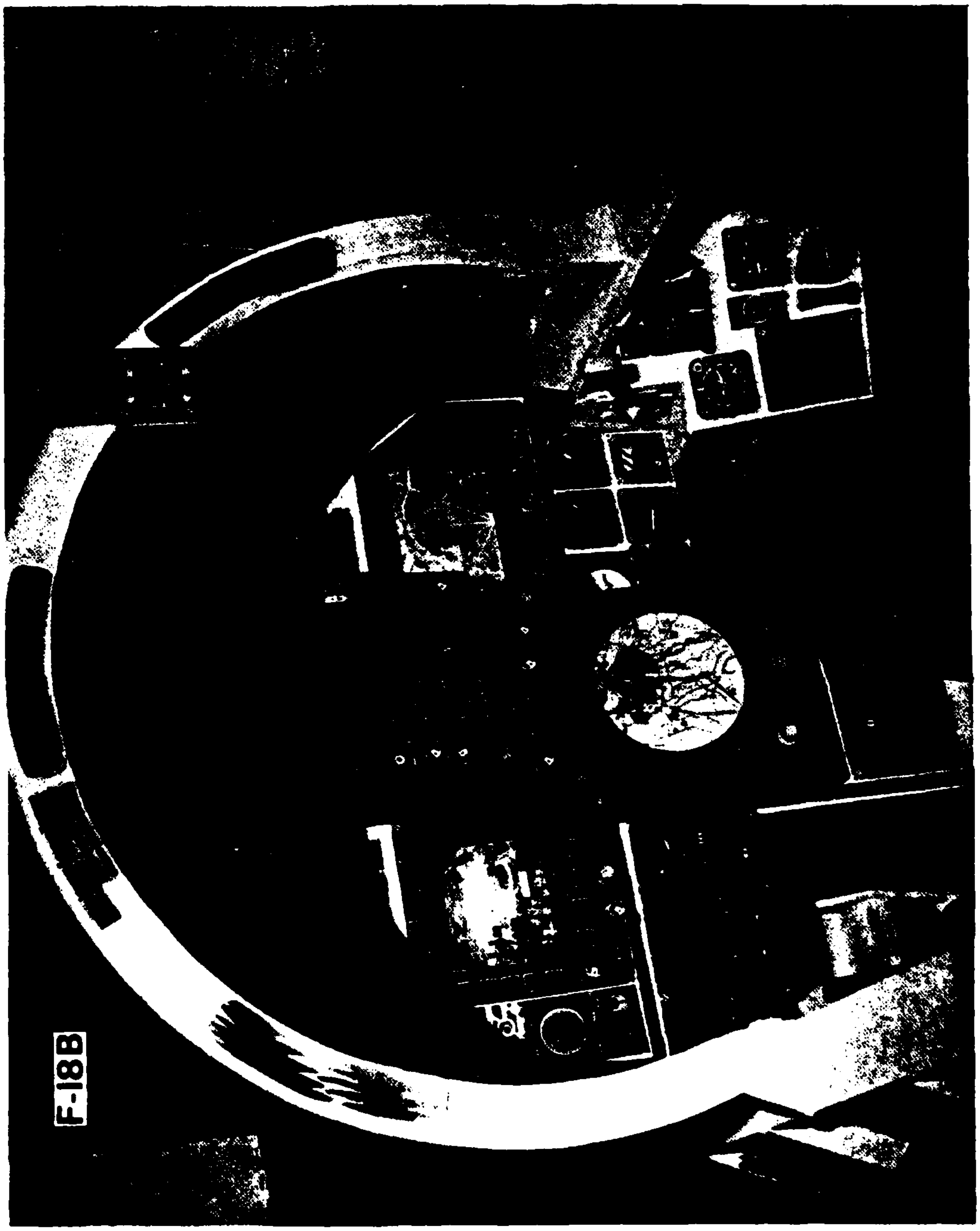


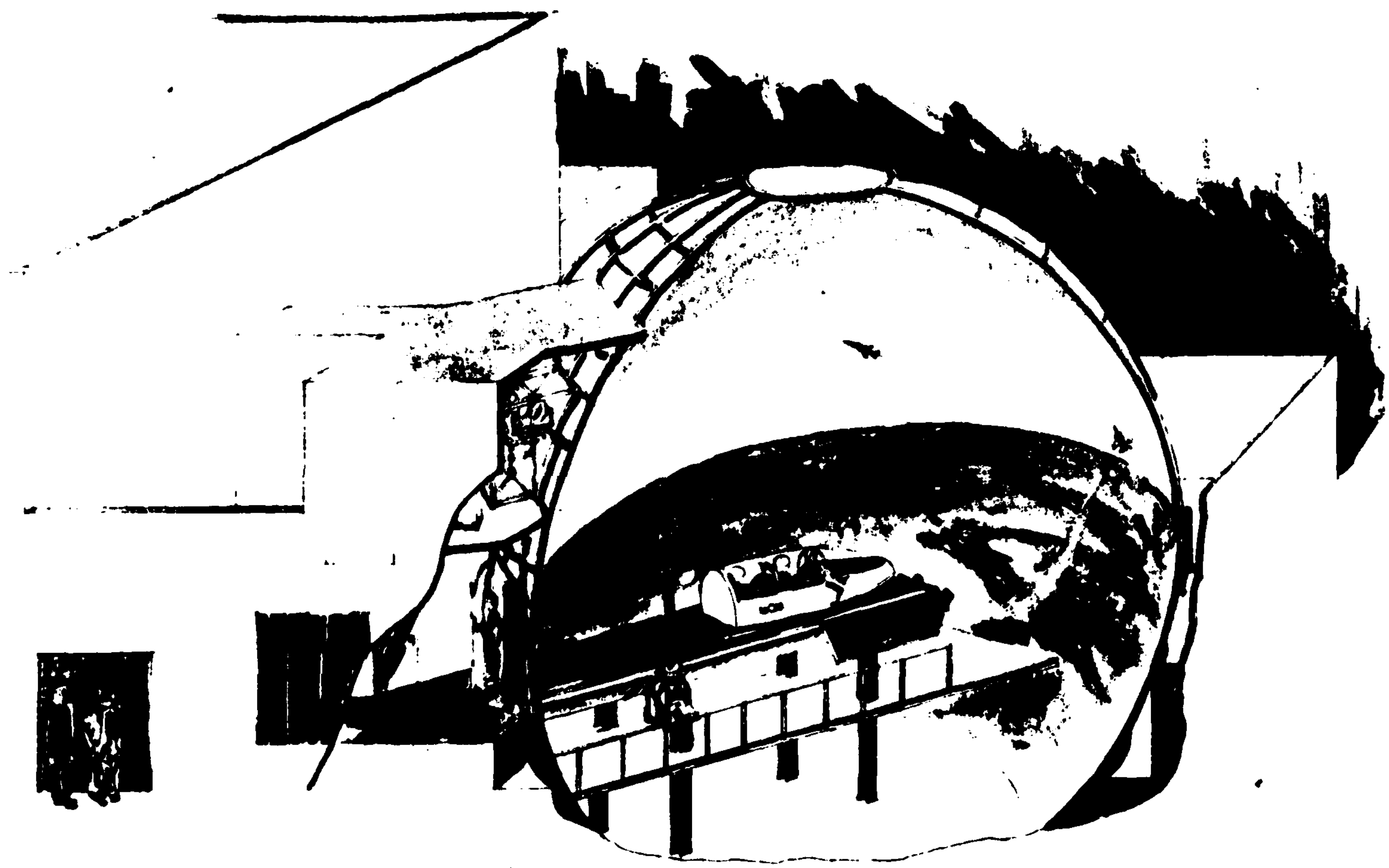
GP75-0500-541

F-18 CREW STATION FUNCTIONAL RELIABILITY

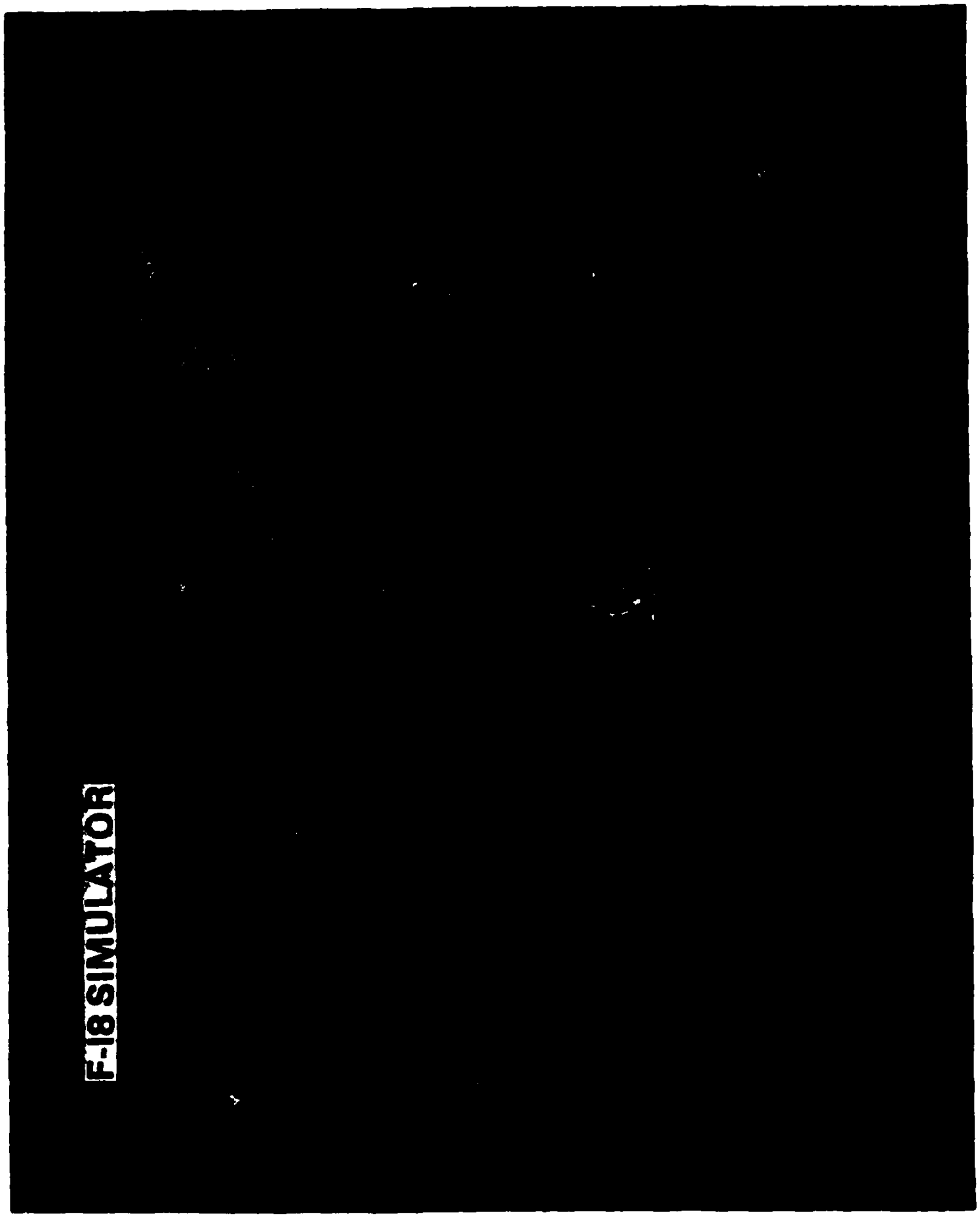



F-18A


F-18B



MANNED AIR COMBAT SIMULATOR (MACS III)


F-18 SIMULATOR

ONE-MAN-OPERABILITY

- SENSORS/WEAPONS
- CNI
- MODING

GP75-0500 1041

ONE MAN OPERABLE WEAPON SYSTEM

PROBLEM

- HIGH WORKLOAD ITEMS
  - 1) WEAPONS/SENSORS
  - 2) CNI
  - 3) MODING

(3) A/A WEAPONS
(72) A/G WEAPONS
(20) SYSTEMS
(3) PRIMARY MODES
(250) SWITCHABLE FUNCTIONS

- INFORMATION EXPLOSION
  - CLUTTER CONTROL
  - SCAN PATTERNS

- SMALLER COCKPITS
  - INCREASED VISIBILITY OVER NOSE AND SIDE
  - SMALLER CONSOLES AND INSTRUMENT PANELS

MCDONNELL AIRCRAFT COMPANY
GP75 0100 369

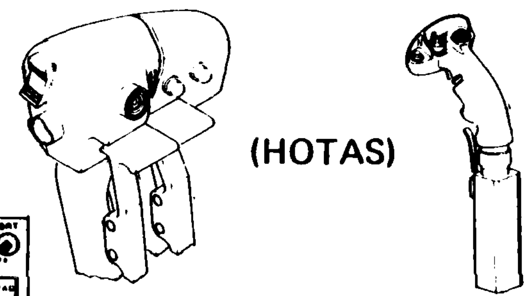
ONE MAN OPERABLE WEAPON SYSTEM

APPROACH!

MINIMIZE CONSOLE ACTIVITY THROUGH:

I WEAPON/SENSOR MANAGEMENT

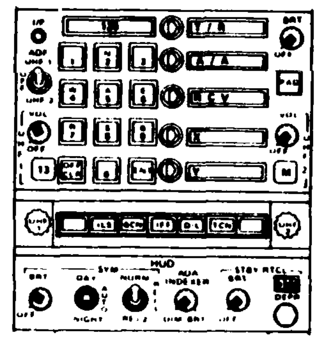
- HANDS ON THROTTLE AND STICK



(HOTAS)

II CNI MANAGEMENT

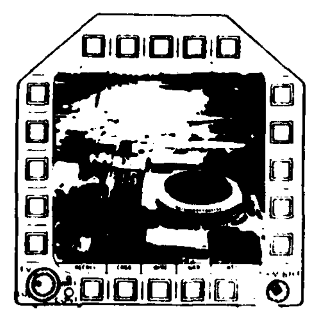
- UP-FRONT CONTROL



III AIRPLANE MODE CONTROL

- AIR-TO-AIR
- AIR-TO-GROUND
- NAVIGATION

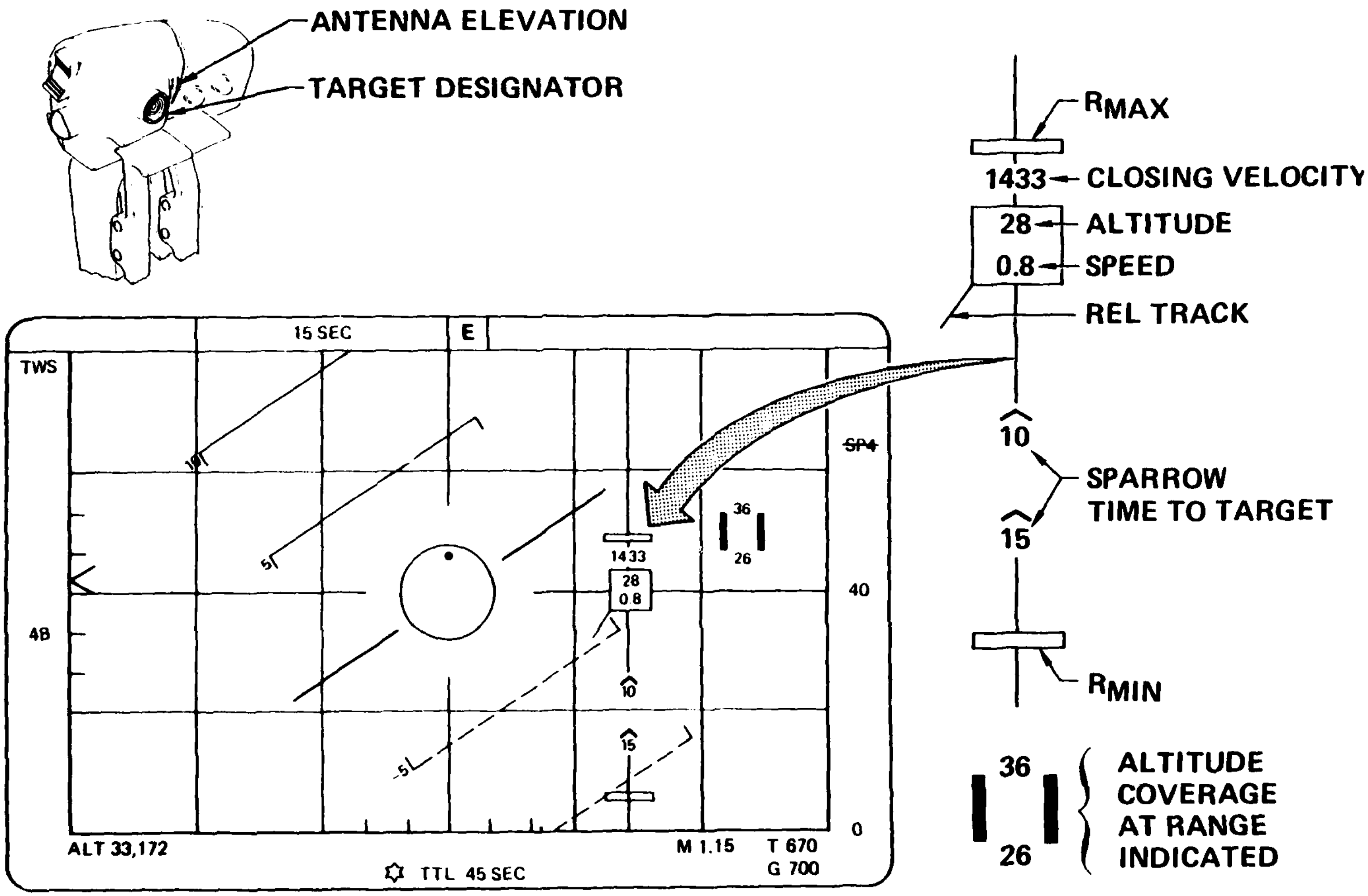
MASTER MONITOR MODING



GP75-0100-370

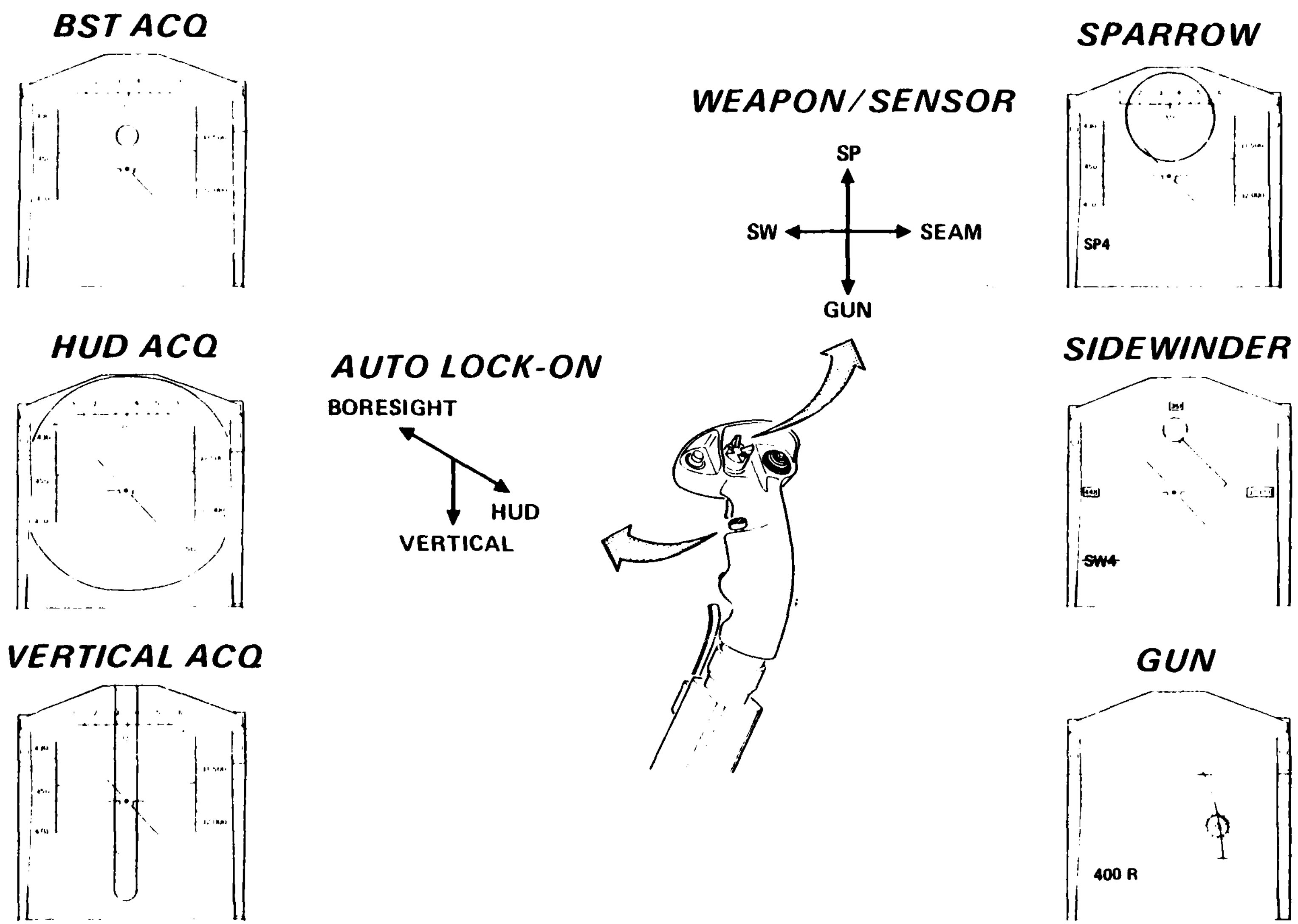
Aircraft

RADAR-IDENTIFICATION CONTROLS



GP75 0700 1274
3 Dec 1976

# HOTAS
SELECTION = SENSOR/DISPLAYS MANAGEMENT



31 DEC 1975

COMM-NAV-IDENT MANAGEMENT

VIA

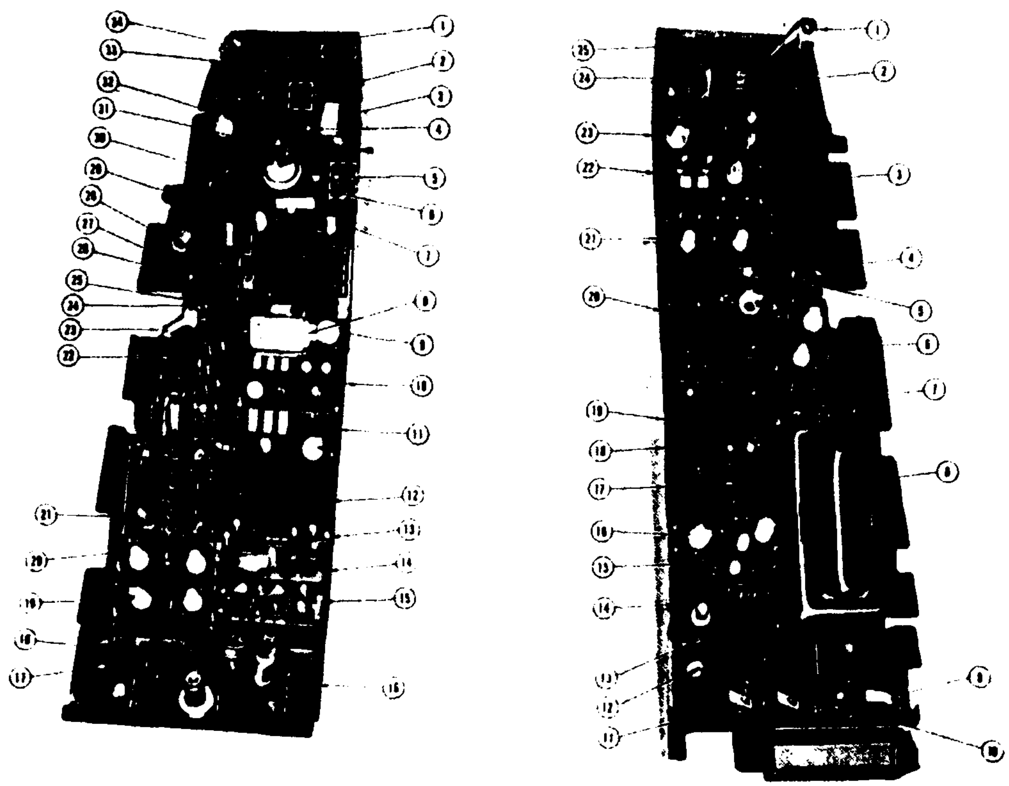
UP-FRONT CONTROL

MCDONNELL AIRCRAFT COMPANY

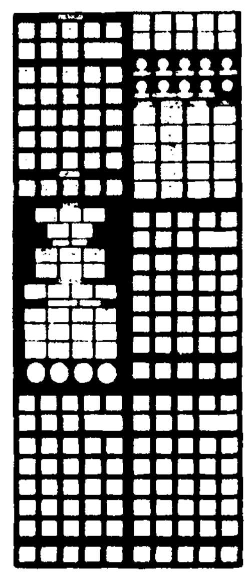
GP75-0100-518

SEPARATE vs INTEGRATED CONTROLS

Console Clutter Example

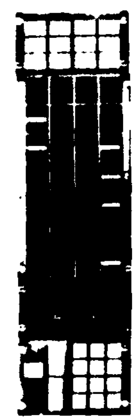


Integrated Controls by Function



4 sq ft

Complete Integrated Controls

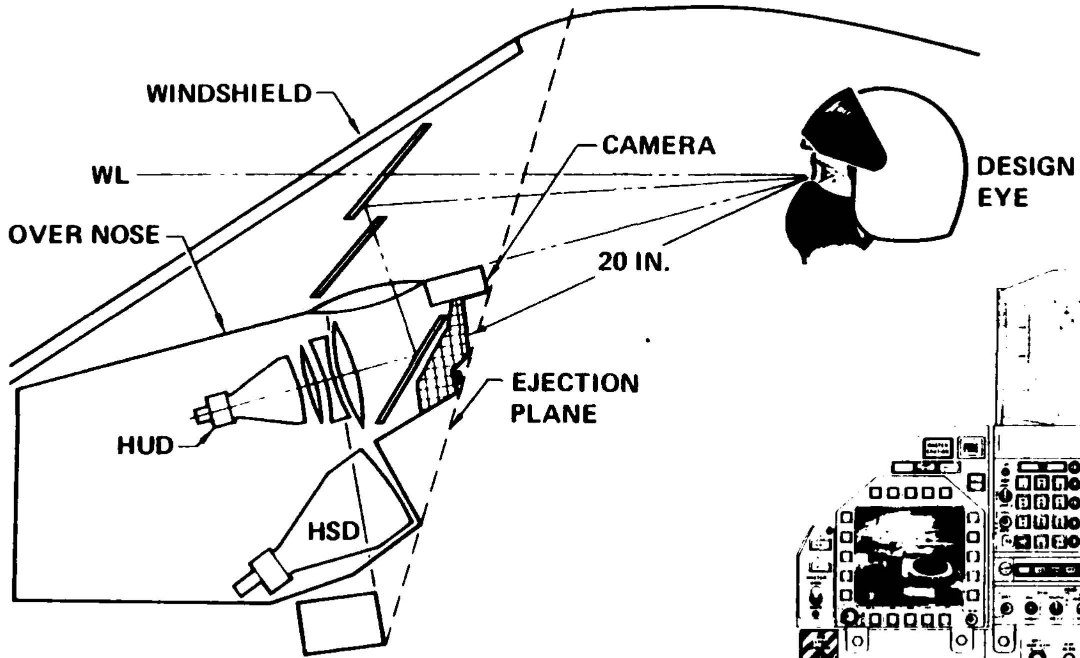


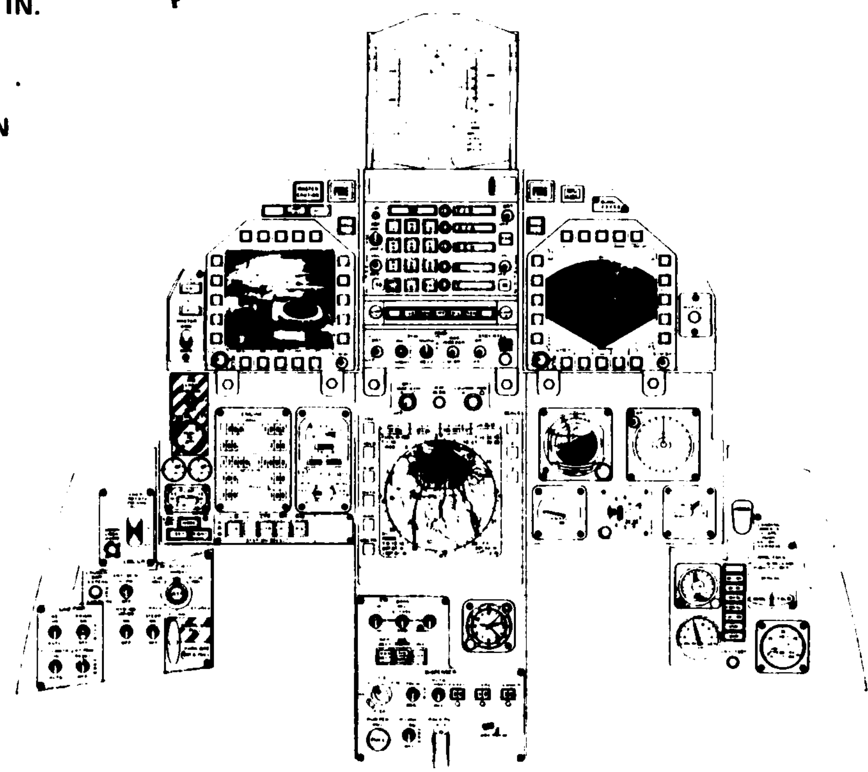
1 sq ft

Note: Numbers indicate panels and related functions.

GP74 1000 154

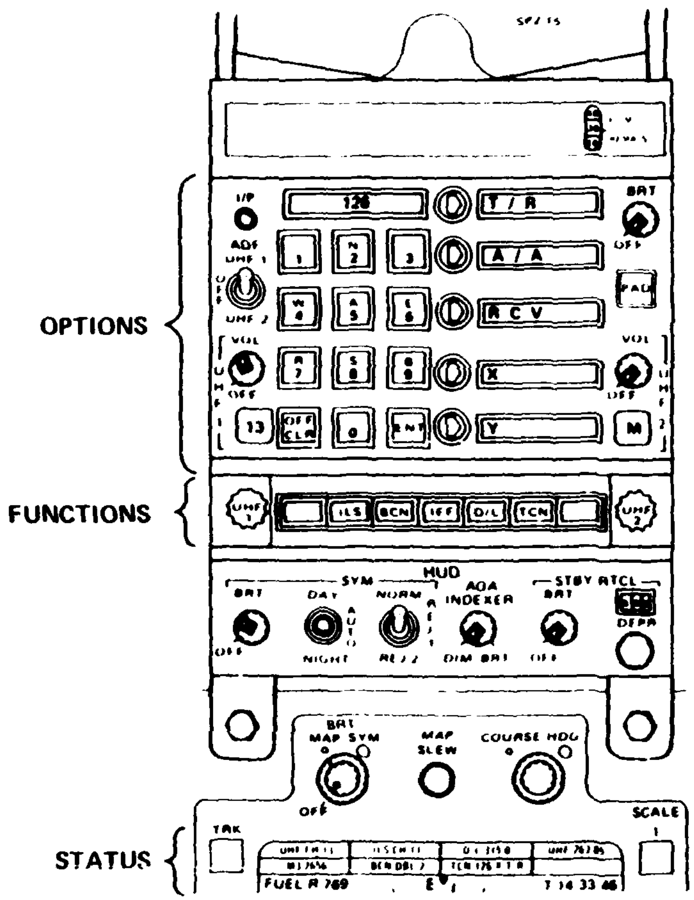
HUD-HSD
CRT MECHANIZATIONS





MCDONNELL AIRCRAFT COMPANY
GP75-0100-474

UP FRONT CNI CONTROL



. ALLOWS:

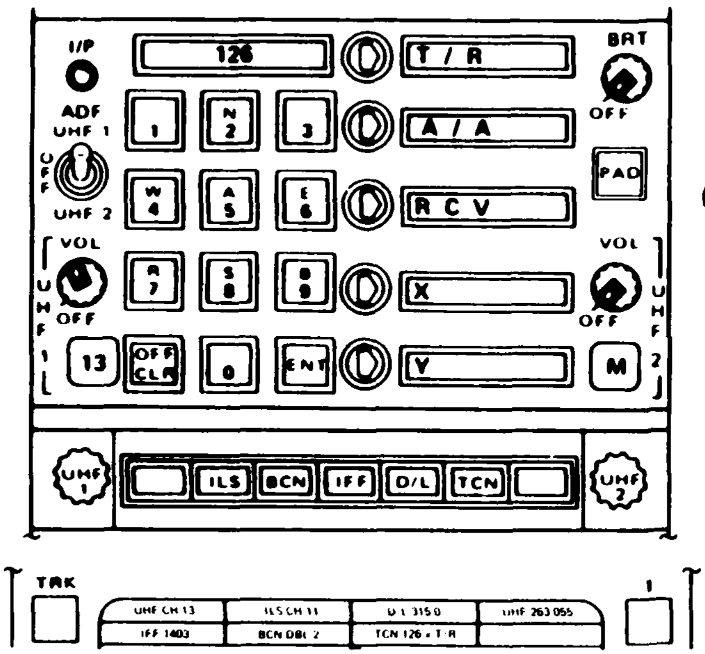
- HEAD-UP
- EITHER HAND
- NONVERTIGO INDUCING OPERATION
- FULL STATUS DISPLAY OF

SPECIAL FEATURES:

- UHF-CHANNEL KNOBS, VOLUME, BRIGHT UP
- ANY ORDER ENTRY
- NO DECIMAL POINTS
- REJECTS NONALLOWABLE ENTRIES
- OFF EXCEPT WHEN IN USE
- RAPID FUNCTION OFF
- SWITCH OF THE MOMENT (SOTM)

GP75 0100 473

UP-FRONT CONTROL
TACAN

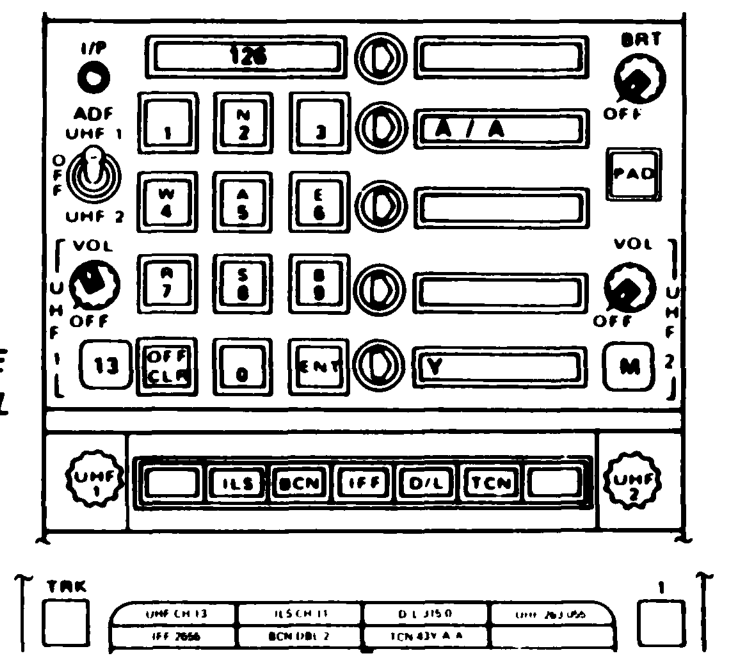


(1) SELECT TCN

- **OPTIONS APPEAR**

(2) SELECT MODE AND CHANNEL

(3) ENTER



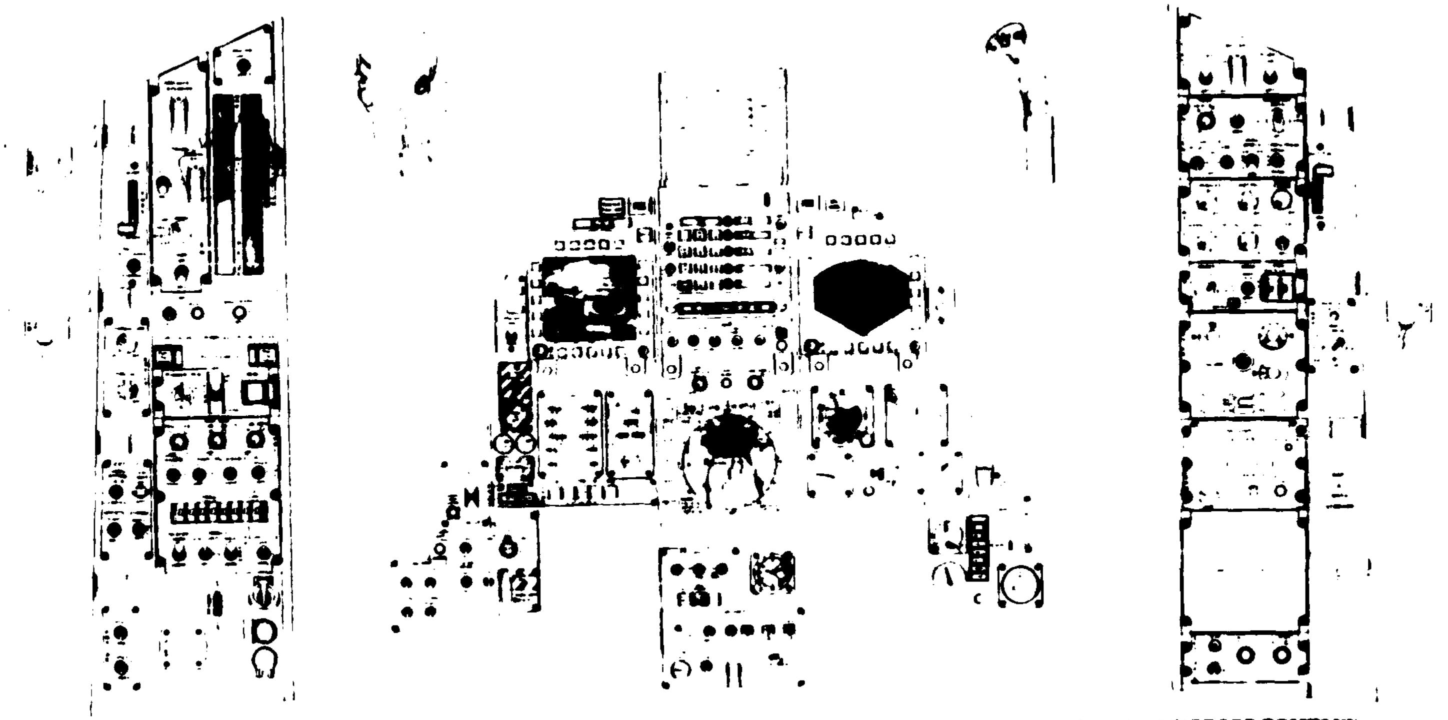
MCDONNELL AIRCRAFT COMPANY
GP75 0100 901

UP-FRONT CNI

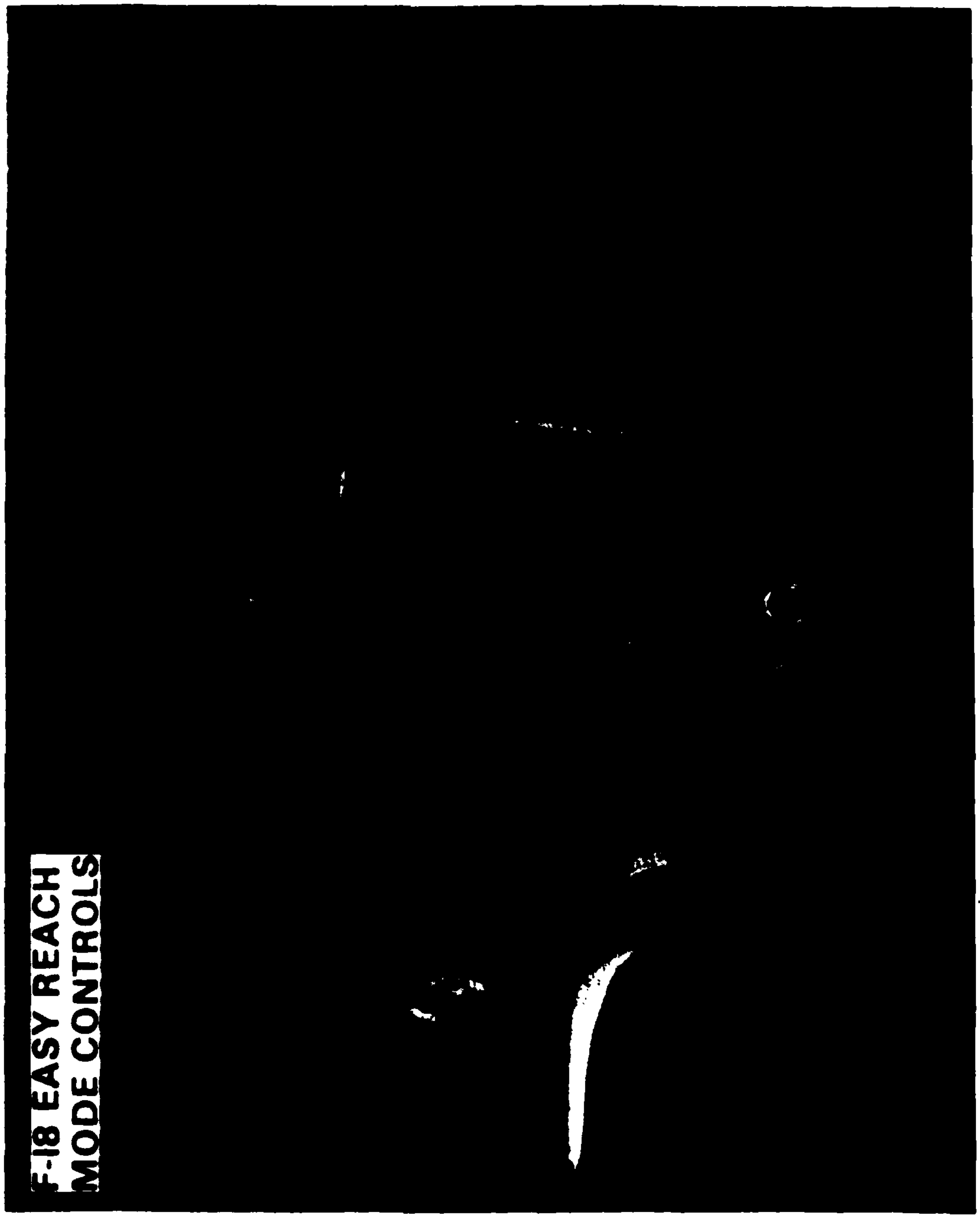
HEAD-UP IFR CONTROL AND DISPLAY

PROVIDES:
- HEAD-UP
- EITHER HAND OPERATION
- HAND REST

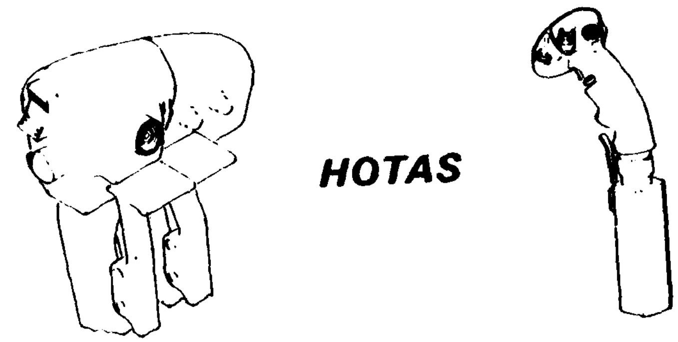
REDUCES:
- SPATIAL DISORIENTATION
- CONSOLE AVIONICS
- WEIGHT/POWER/COST



MCDONNELL AIRCRAFT COMPANY


F-18 EASY REACH
MODE CONTROLS

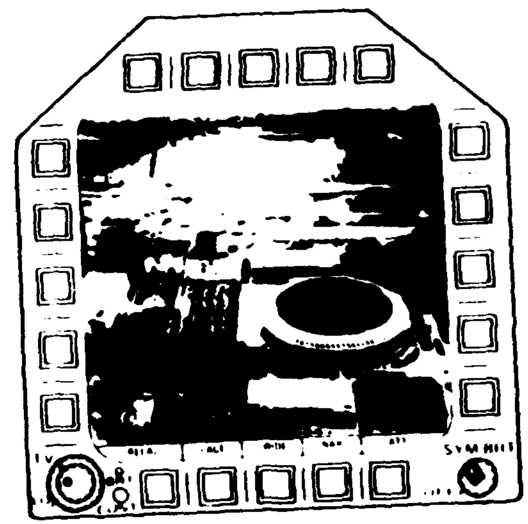
F-18 MODE CONTROL



HOTAS

(1) AIR-TO-AIR VIA

MASTER MONITOR DISPLAY



(MMD)

(2) AIR-TO-GROUND

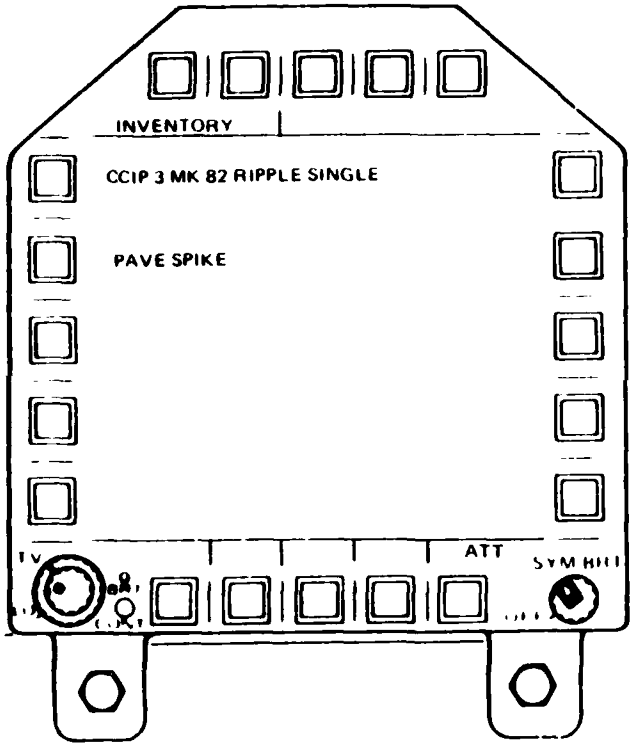
(3) NAVIGATION

VIA

GP75 0500 949

MASTER MONITOR MODE CONTROL

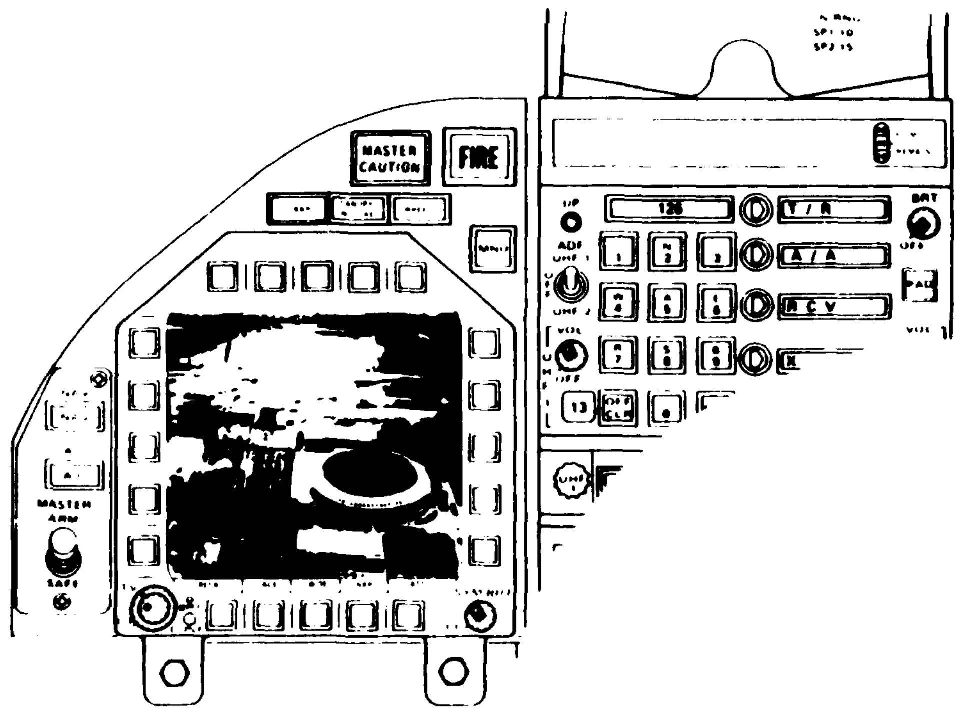
(A/G) PAVE SPIKE POD



1) SELECT A/G

- ***OPTIONS APPEAR***

2) SELECT PAVE SPIKE



3) SELECT

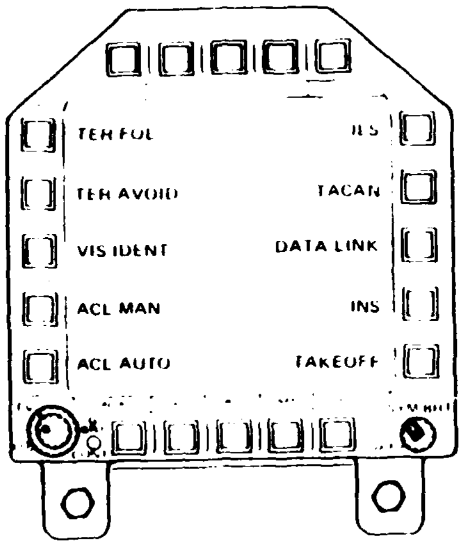
- ***MODE***
- ***CODE***
- ***ALTITUDE***

- All Selections Head/Hands Forward

MCDONNELL AIRCRAFT COMPANY

MASTER MONITOR MODE CONTROL

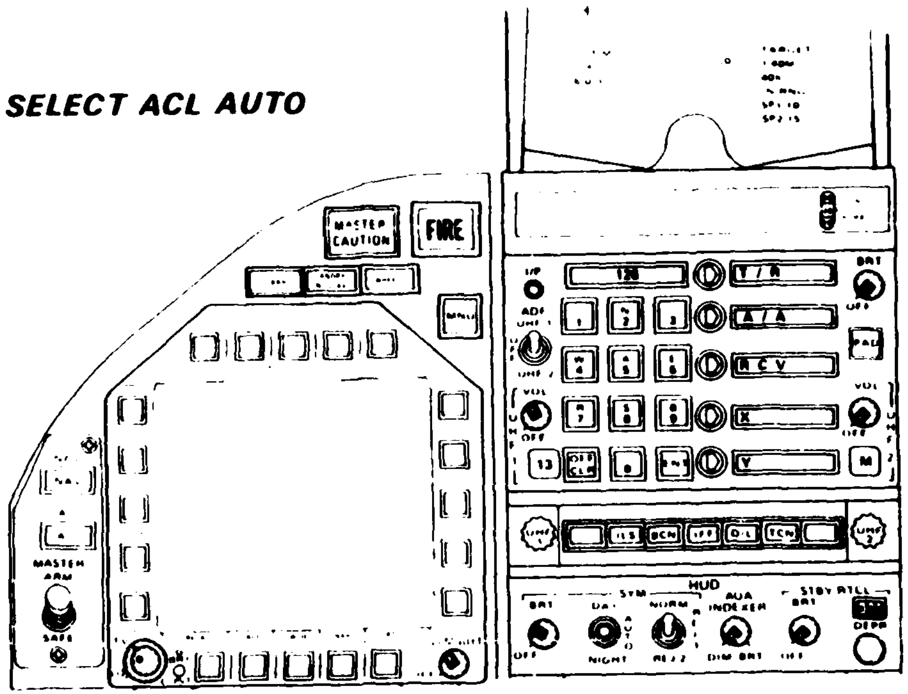
(NAV) AUTO CARRIER LAND



1) SELECT NAV

- ***OPTIONS APPEAR***

2) SELECT ACL AUTO

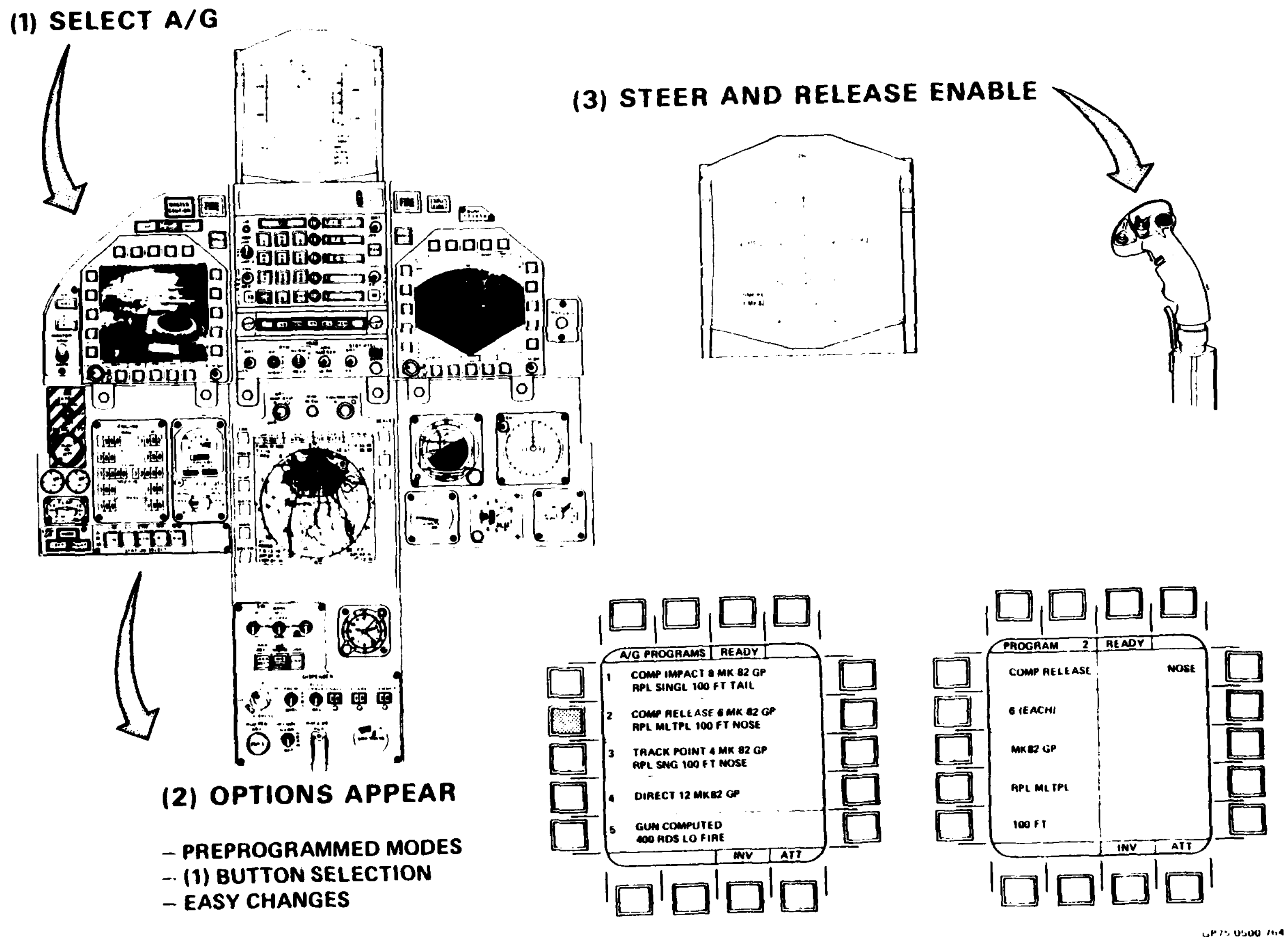


3) ACL AUTO OPTIONS APPEAR ON MMD AND UP-FRONT

- All Selections Head/Hands Forward

GP78-0100-503

A-18 ARMAMENT CONTROL

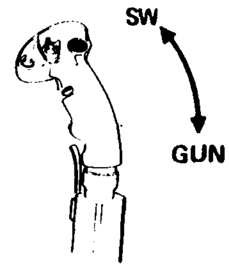


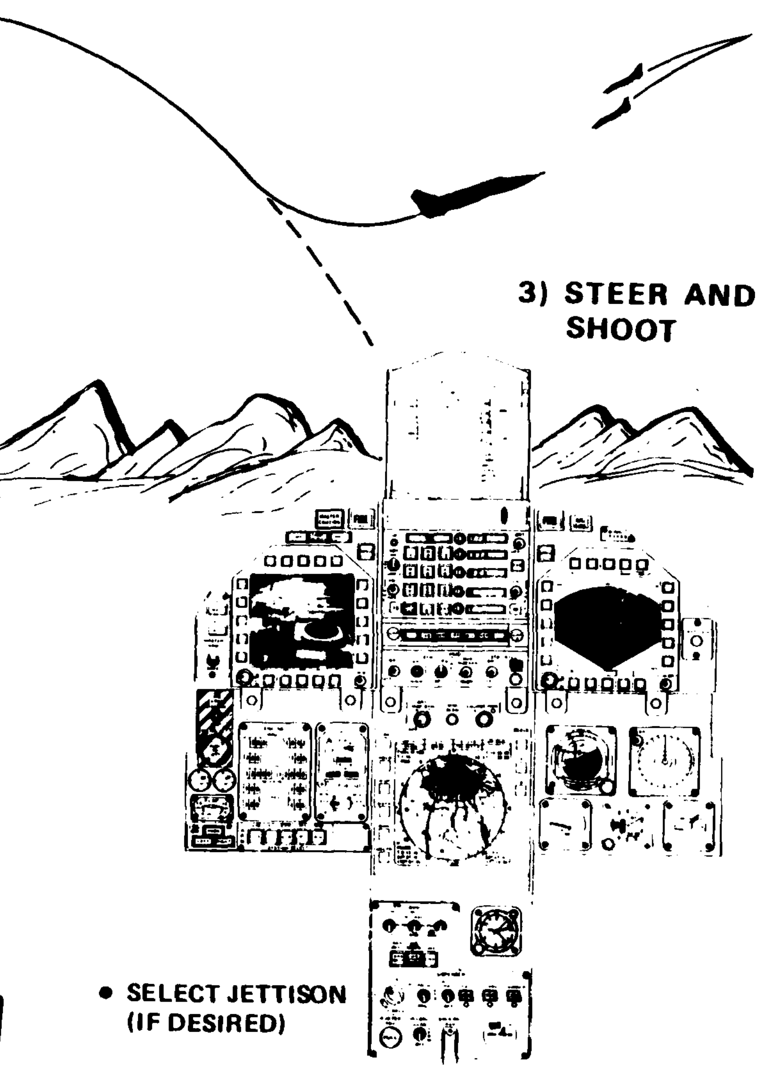
GP75 0500 764

VA-1 SELF PROTECTION

ONE SWITCH AIR-TO-AIR

1) SELECT GUN OR SW



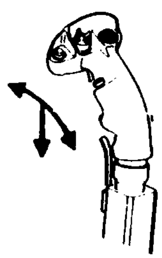


- SENSORS/DISPLAYS AUTOMATICALLY SET UP

	RG	AZ	EL
GUN	5	20°	20°
SIDEWINDER	20	140°	4 BAR

MISSION COMPUTER → DISPLAYS

2) AUTO LOCKON
- BORESIGHT
- SUPERSEARCH
- VERTICAL SCAN



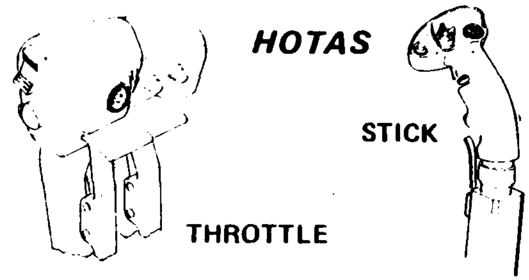
- SELECT JETTISON (IF DESIRED)

GP75 0500 733

ONE MAN OPERABLE WEAPON SYSTEM

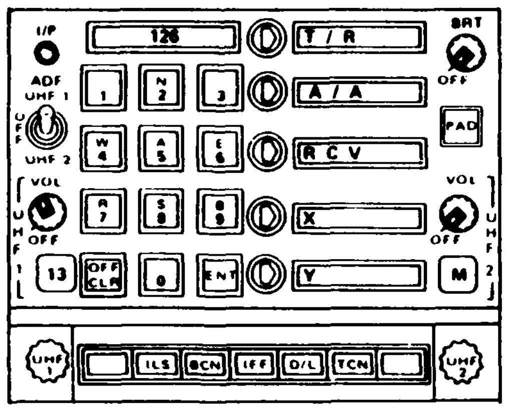
SUMMARY

I WEAPON/SENSOR MANAGEMENT



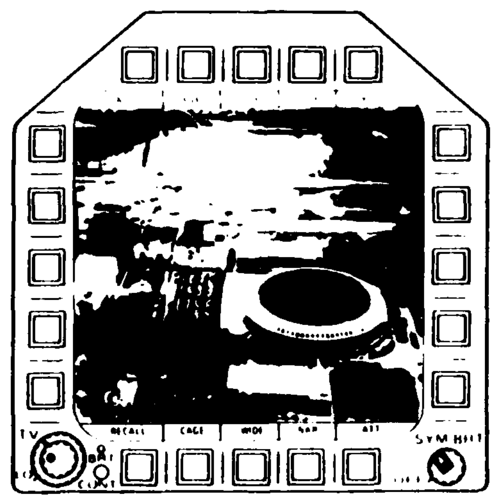
II CNI MANAGEMENT

UP-FRONT CONTROL



III MASTER MONITOR MODING

MASTER MONITOR DISPLAY



GP76 0448 15

THE MANEUVERING FLIGHT PATH DISPLAY

J. F. Watler, Jr.
NORTHROP CORPORATION, Aircraft Division
Hawthorne, California

G. W. Hoover
Consultant

ABSTRACT

The aircraft man-machine interface, in general, has failed to keep pace with advancements in airframe dynamic performance. This deficiency has given rise to a notable anomaly in total system performance capability. Nowhere is the anomaly more apparent than in today's fighter aircraft where the pilot, by virtue of the man-machine interface limitations, is unable to safely and consistently obtain from the machine all of its available capability.

It was concluded that the best means of improving the man-machine interface was to develop new "integrated" visual displays. Integrated displays are defined as those which present only "solution" information. By solution information, we mean that information which represents the solution to an equation rather than the parameters, or variables, involved in the equation. Further, this solution information is always presented in a display format which is natural and to which a human responds rapidly, accurately, and consistently. Integrated displays have been found to be particularly effective in the more dynamic flight situations.

Northrop has initiated an independent research and development program in the area of integrated displays. One of the concepts under evaluation and development is the "maneuvering flight path" display. Previous studies performed during the 1950's demonstrated the desirability and effectiveness of the display, but technological limitations precluded its earlier development. Northrop has extended the earlier work on the concept and has devised a feasible means of mechanizing it as a cockpit display. This paper describes the maneuvering flight path display concept and reports on the status of the display's development.

1.0 INTRODUCTION

This paper reports on an advanced aircraft display concept, known as the Maneuvering Flight Path Display, which is currently under development at the Northrop Corporation Aircraft Division. The basis of the concept, the functions and characteristics of its elements, its projected applications, and its information content will be discussed. The implementation of the concept and its development to date will be described, along with the activities planned to establish conclusively its operational feasibility. The maneuvering flight path display will be useful in all modes of flight, but it is being mechanized with special emphasis on its application to air combat maneuvering (ACM). For that reason, the display is described mainly in the ACM context.

1.1 BASIC REQUIREMENTS

When we speak of "advanced" aircraft display concepts, we refer to concepts which are philosophically different from the accepted conventional displays and which are not currently in use. However, we are aware of the ambiguity of the term

"advanced." For almost as long as we have had airplanes, every new development in the field of cockpit instrumentation has been heralded as "advanced." And yet, the display concepts in today's aircraft have not changed significantly in the last fifty years. Therefore, let us take a little time to develop the rationale for the Maneuvering Flight Path Display concept, and let the discussion of the display per se proceed logically from there. Specifically, we shall examine the needs for such a display and the considerations which specifically dictate a "flight path" — in other words, the basic requirements.

While the needs which led to the flight path display concept are numerous, they can be summarized under three categories: greater system performance, increased flight safety, and decreased crew training.

1.1.1 Greater System Performance

In the case of combat aircraft, greater system performance is synonymous with better mission results. Looking across the board at the variety of missions involved, it is clear that the air-to-air engagement, or ACM as it is popularly called, is by far the most demanding on the man as well as the machine. Indeed, no other mode of flight expresses the need for a sensitively designed man-machine interface more forcefully than ACM. On the matter of providing greater system performance, we reached several conclusions that served to direct our effort. These conclusions are:

1. The flight mode in which greater system performance is most critically needed is ACM.

2. A significant increase in system performance during ACM can be provided via improvement of the man-machine interface (i.e., the cockpit controls and displays).

3. The task of providing greater system performance by means of improved controls and displays is more difficult for ACM than any other flight mode, but resolution of the ACM problem implies the almost automatic resolution of the others.

Two major, continuously recurring questions confront the pilot during ACM: "what should I do?" and "how should I do it?" During ACM, the former relates to tactical performance; the latter to dynamic performance.

Today's sophisticated avionics systems notwithstanding, air-to-air engagements are still being carried out much as they were in World War I (i.e., by maintaining "eyeball-to-eyeball" contact with the adversary). Yet, today's operational fighter pilot will readily agree that he needs more "what should I do?" information than he is able to obtain by direct visual contact alone.

Similarly, the present generation of fighters afford levels of dynamic performance which pilots are generally unable to achieve with the "how should I do it?" information available from present cockpit displays.

Clearly then, a distinct tactical edge could be provided if all of the essential "what should I do?" and "how should I do it?" information could be effectively communicated to the pilot. Present multisensor and airborne computer technologies permit the high-speed data acquisition and computation necessary to determine the required information. What is lacking is a display which will effectively communicate the information to the pilot.

The display must allow the pilot to control the aircraft effectively while keeping his head up and moving. It must simultaneously present all of the operationally required ACM information such as aircraft performance limits, energy management, tactical data, fire control, and critical system states in such a manner that the pilot can easily understand the situation at hand and anticipate progressive developments.

1.1.2 Increased Flight Safety

Obviously, any display which provides a "tactical edge" during ACM affords the pilot a significant measure of safety in that mode. Unfortunately, our losses of aircrew and aircraft are not confined to combat. Many losses still occur during landings and takeoffs. Furthermore, recent aircraft accident statistics indicate that a large number of accidents are still resulting from either the inadequate presentation or the total absence of the required information. Such causal factors as stall/spin, pilot disorientation, and loss of control could be more accurately identified as "lack of necessary information."

What then are the implications of flight safety considerations in terms of basic requirements for an ACM display? First, the primary display should be the same for all flight modes. This is logically consistent since any display capable of meeting the severe dynamic control requirements of ACM should be suitable for all other flight modes as well. The display must incorporate such functions as necessary to present in each flight mode all of the information which is operationally required in that flight mode. Thus, for example, Instrument Landing System (ILS) glideslope and localizer as well as necessary flight control information would be presented during landing. Again, the information would have to be presented in such a way that its ready assimilation and anticipatory use by the pilot is assured.

1.1.3 Decreased Crew Training

Separate studies have shown that no human is capable of performing the computations which would be required if all crew decisions during ACM were to be based on unique, logical solutions of the equations involved. As a consequence, pilots and radar observers involved in ACM are now compelled to train continually in ACM to develop and maintain their proficiencies in making highly accurate intuitive judgments under stress. This training is presently expensive and time-consuming, and will become even more expensive as fuel prices increase. Ways to reduce training are constantly being explored.

An ACM display is intended to relieve the pilot of the burden of having to make the innumerable real-time judgments associated with air engagements. If the display can prove successful in that capacity, it follows that it will also have a favorable effect on training requirements. As a goal, therefore, the display should be capable of being flown satisfactorily by pilots of limited experience with only a nominal amount of aircraft transition training. Further, it should reduce crew workload sufficiently to permit the average pilot to achieve a higher-than-present level of ACM proficiency. It must also facilitate crew ACM training by simulators.

1.2 THE FLIGHT PATH DISPLAY CONCEPT AND ITS ORIGIN

The flight path display concept is not just another cockpit invention. Rather, it is the product of an extended program of careful research into the aircraft man-machine interface. The discussion which follows briefly describes the origin of the concept.

1.2.1 The Integrated Visual Display Approach

The concept of an electronically generated cockpit visual display which would present a command flight path to the pilot is not new. The concept was one of the products of the Army-Navy Instrumentation Program (ANIP) in the 1953-1963 period. The display was envisioned as a real-time, geometrically faithful representation of a "highway in the sky," over which the pilot could fly his aircraft. The flight path display concept was the result of strict adherence to two basic ground rules. These ground rules, validated by previous studies, may be simply stated as:

1. The information displayed should present the solution to a problem rather than the state of the variables involved.

2. The information should be presented in a format that a human being understands and reacts to naturally.

The first ground rule merely recognizes the respective characteristic capabilities and limitations of man and machine, and prescribes that the pilot displays be designed accordingly. In other words, the pilot should be told what to do and how to do it with enough information on the prevailing situation to enable him to accept or reject the instructions.

The second ground rule recognizes that man, as a consequence of his total experience, reacts predictably to certain factors in his natural environment and prescribes that the pilot displays be designed to exploit this characteristic. Let us take a closer look at this matter. Five basic visual cues are involved in contact flying. It is on the basis of these cues (noted parenthetically below) that student pilots learn to fly. As the fledgling pilot is given the controls for the first time, he is advised to maintain the horizon (the external reference) in a particular position relative to the frame of the windscreen (the internal reference). He unconsciously detects and identifies objects by their appearance (surface texture), and he learns to judge distance from the varying size of familiar objects (linear perspective). He learns to assess his attitude as well as his ground speed through the apparent differential motion of elements at different distances within his field of view (motion parallax). Even a student pilot, after very little indoctrination on the flight controls, uses these cues effectively to maintain his spatial orientation. A case in point is the effectiveness of recovery from an unusual attitude once visual contact with the ground is reestablished.

The flight path display is a natural "solution" display in that it simultaneously presents "what to do" as well as "how to do it" information. Further, the five basic visual cues cited above are inherent in the presentation of an electronically generated, dynamic (or maneuvering) flight path on a head-up display.

The ability to include all of the flight control solutions data and the required visual cues in a pictorial display format led to the identification of these visual displays as "integrated." In recent years, the term "integrated" has been used to describe electronic displays in which isolated parametric and/or "solution" information is combined and presented in either an abstract or a symbolic display format. We prefer to identify these displays as "combined" displays. Figure 1 graphically portrays our definition of "combined" and "integrated" head-up displays. In practice, integrated displays have been found to afford a more rapid and accurate pilot response to display changes. Accordingly, it was reasoned that integrated displays would prove to be particularly effective in the more dynamic flight situations such as ACM. However, a basic constraint under which the flight path display concept materialized and evolved was that the selected display had to be usable and equally effective in all

modes of flight. In other words, the same display had to be used in takeoff, cruise, ACM, air-to-ground strike, traffic control, and landing.

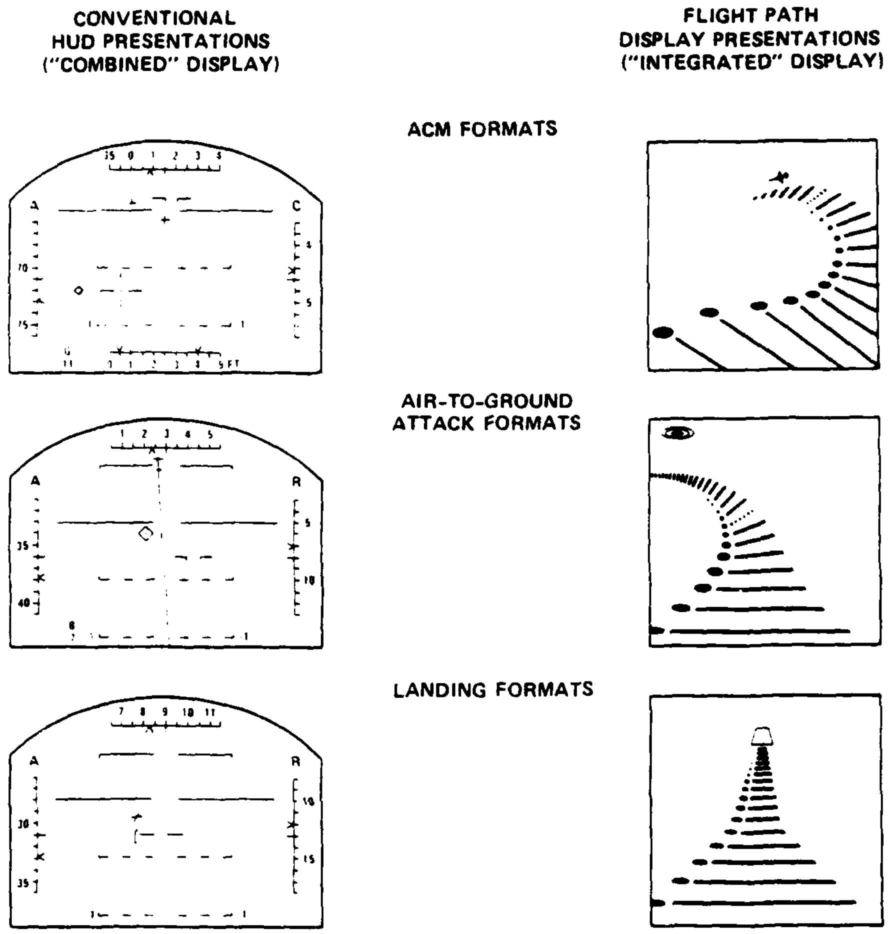


FIGURE 1. "COMBINED" VS "INTEGRATED" DISPLAYS

1.2.2 Developmental Background of the Flight Path Display

Preliminary laboratory simulation studies of the flight path display were conducted in the 1950's. These studies demonstrated the desirability and utility of the display in applications requiring precise control of vehicle trajectory. However, prevailing technological limitations precluded development of the flight path display at that time. To our knowledge, no further work was done to develop the concept until we began our reexamination of it in the course of a study to define ACM display requirements.

2.0 THE FLIGHT PATH DISPLAY

Although the Maneuvering Flight Path Display is simple in format, it incorporates a wealth of essential pilot information and warrants further discussion. Accordingly, let us now examine the nature, the functions, and the characteristics of its elements at some length and assess its functional capabilities and related information content.

2.1 THE DISPLAY ELEMENTS

The display, as it is currently structured, consists of three display elements as shown in Figure 2. The detailed characteristics of the elements are still tentative and will remain subject to change until such time as the scaling and display dynamics studies are complete. However, as presently conceived, the flight path display will be made up of a series of moving line elements analogous to "tar strips" on a highway, a series of "speed index" elements which move relative to the tar strips, and "target aircraft" representations which grow in size as range closes. The intent is to generate the display on a head-up display (HUD). Thus, the present objective is to provide a display which will keep the pilot's field of view as uncluttered as possible. Otherwise, textured elements such as shown in Figure 3 could be used instead of tar strips.

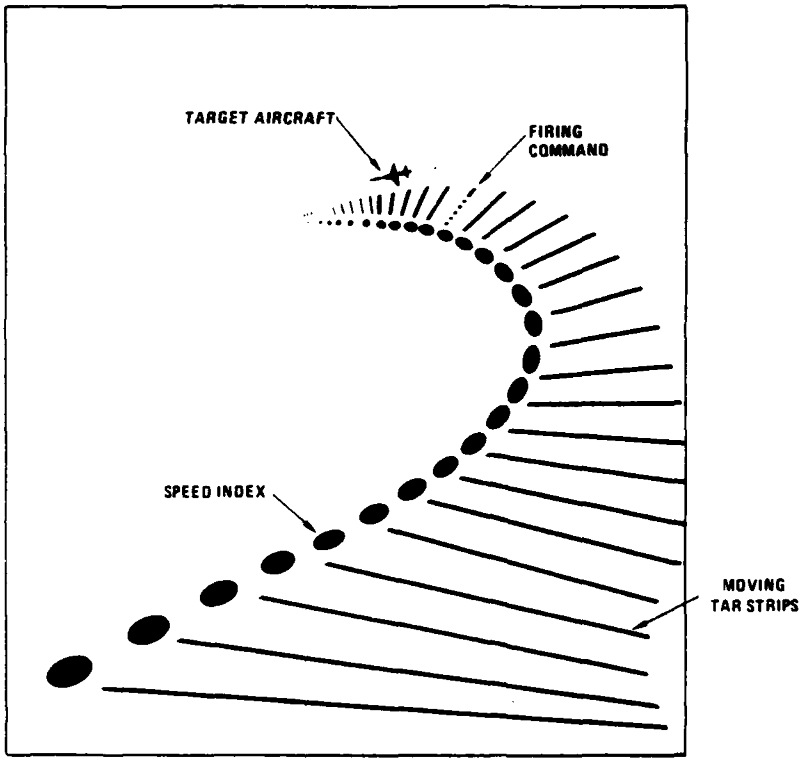


FIGURE 2. MANEUVERING FLIGHT PATH DISPLAY ELEMENTS

The tar strips and speed index will extend out in front of the aircraft and will be displayed to the pilot with complete geometric fidelity. Thus all elements will appear with proper perspective. The flight path will be displayed as though the aircraft is taxiing on it. Hence the tar strips will appear to move under the aircraft at a speed proportional to airspeed. A specific tar strip, or tar strips, can be uniquely identified (as the broken line tar strip of Figure 2) to denote discrete command points such as weapon firing or release points. The speed index will be used to provide precise speed control. If the aircraft is too fast, the elements of the speed index will appear to be overtaken and passed; if the aircraft is too slow, the elements will appear to outrun the aircraft. When the aircraft is flying at the proper airspeed, the elements will not move and it will appear to the pilot that he is flying formation with them.

The flight path will be fully maneuverable. Accordingly, it will provide attitude, heading, and altitude information at all times. Although this information is qualitative,

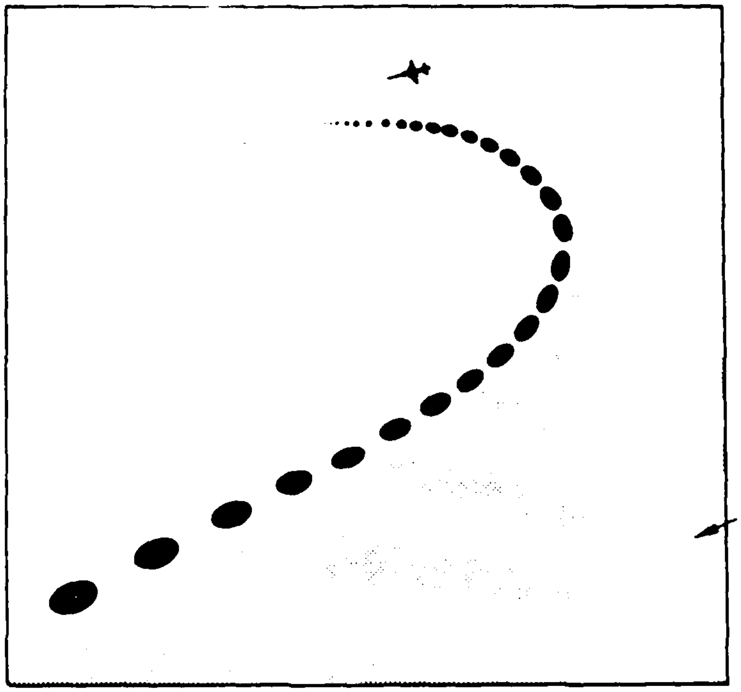


FIGURE 3. FLIGHT PATH WITH TEXTURED ELEMENTS

it is accurate and completely adequate for precise control. Through its display of attitude information, the flight path will also provide the pilot with essential information on his velocity and normal acceleration (V-N) state. Simply stated, as long as the pilot stays on the flight path, he knows that he can never exceed the V-N limits of his aircraft. Similarly, since the flight path contains all of the related information (i.e., speed, altitude, and attitude) *it will automatically provide all of the pertinent* energy management data the pilot needs.

A simple representation of the target aircraft will complete the display as presently planned. The representation is not yet fully defined, but it will vary in size perspectively as the distance to the aircraft it represents varies. It will always be positioned to show the location of the target aircraft in the field of view. Similarly, representations of ground targets and runways can be provided in the air-to-ground strike and landing modes, respectively, such as shown in Figure 1.

2.2 INCORPORATION OF SYSTEM FUNCTIONS

We elected to attack the ACM display problem first because we believed that its successful resolution would mean the almost automatic resolution of the display problems of the other modes. The ACM display must help get the pilot to the combat area and back to base again, as well as assist him during the actual engagement. Thus, it must provide information on the following wide variety of system functions:

1. Tactical Control
2. Aircraft Performance Control
    a. Fuel Management
    b. Energy-Maneuverability
    c. Performance Limits (V-N)
3. Fire Control/Weapon Delivery

4. Navigation/Traffic Control

Let us take a brief look at how each of these functions will be accommodated in the maneuvering flight path display.

2.2.1 Tactical Control Information

The maneuvering flight path display will be capable of responding to any threat on which information is available. However, the flight path must have the same dynamic limitations as the aircraft for which it is programmed. In other words, the flight path must always display a trajectory which can be flown by the aircraft from its present position and state. It was concluded that the presentation would be particularly well-suited to implementation on a head-up display (HUD). Accordingly, the flight path display will suffer the same field of view limitation as that of state-of-the-art HUD's. Thus, the presentation which the pilot views will include a display of the tactical situation only to the extent that it can be represented in the field of view. Other aircraft within the range of the sensors, and within the field of view, will appear on the display along with the segment(s) of the flight path falling within the field of view at the time. In practice, this will mean that the flight path, in depicting hard turns for example, will proceed out from the aircraft and turn out of the field of view and hence off the display. In the ACM mode, however, enough of the flight path will always be visible to the pilot to enable him to keep the aircraft on it.

The tactics required in a particular ACM situation will be dictated by the relative location, relative direction, and relative energy state of the target aircraft. The flight path display will present the best trajectory for engagement of the nearest target aircraft based on these factors. However, the pilot will be given simultaneously information on the total tactical situation (e.g., the relative positions of other known target aircraft). This will permit him to make the major strategy decisions thereby maintaining overall control. On the basis of this information he may elect to continue the run established by the computer or overrule the system and take another course of action.

In order to present the ACM display in real time, the location of the target aircraft will be predicted. All known aircraft must move from point to point aerodynamically — they cannot translate instantaneously — hence predictions of their paths are relatively simple. These predictions will be updated with each display frame, and will commence anew with each new input from the sensor(s) involved. It is expected that the flight path will significantly reduce pilot reaction time during ACM. Figure 4 shows how the flight path will appear to the pilot in the course of a simple 135° intercept.

Although we have confined our discussion so far to ACM, it is clear that the corresponding tactical information for the air-to-ground mode can be handled just as readily.

2.2.2 Aircraft Performance Control Information

When we speak of aircraft performance information, we refer specifically to that information which enables the pilot to fly his aircraft efficiently. It involves the management of fuel while enroute to the combat area so as to start the engagement with as much fuel as possible. It involves monitoring the remaining fuel during the engagement, and advising the pilot when to break off the fight so that sufficient fuel is available for the return to base (or a suitable alternate). It involves management of fuel while enroute to base (or alternate) so as to arrive with as much fuel as

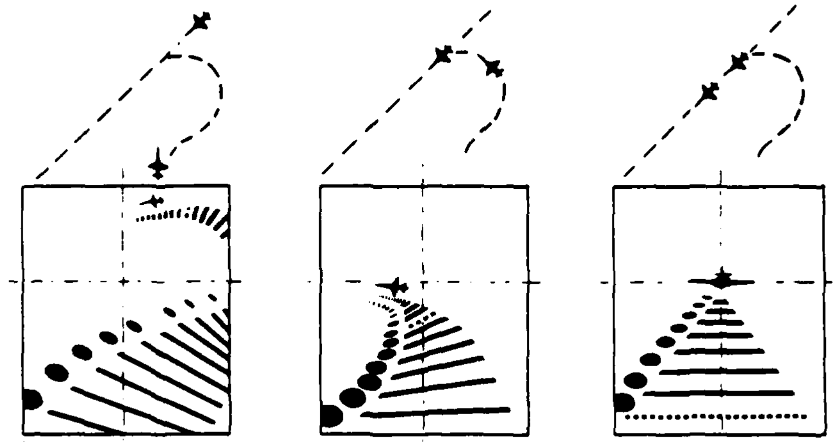


FIGURE 4. TACTICAL SITUATION & CORRESPONDING FLIGHT PATH DISPLAY

possible. It involves maneuvering in combat so as to conserve the potential and kinetic energies of the aircraft. And finally, it involves flying the aircraft up to the limits of its performance, if necessary, without fear of exceeding those limits. Let us examine the structure of the flight path display again to determine how it will present all of this information.

2.2.2.1 Fuel Management Information

There are three fuel consumption modes, or engine power settings, of interest to fighter pilots: "maximum range," "minimum time," and "maximum endurance." On the way to the combat area and while returning to base, the fighter pilot is interested in achieving maximum range per pound of fuel consumed. Therefore, he sets his throttle(s) at the "maximum range" setting. While in ACM, he is primarily interested in executing every action in the least time possible; so he sets his throttle(s) at the appropriate "minimum time" settings. In any "holding" operations, such as those which occur under traffic control conditions, he is interested only in consuming the least amount of fuel per unit time. In this instance he sets his throttle(s) at the "maximum endurance" setting. Each of the three fuel management states involves a unique combination of airspeed, altitude, and engine power for the prevailing mission, system, and atmospheric conditions. Sometimes, for example, the conditions under which the mission must be flown are so restrictive that the pilot can do nothing to optimize his fuel consumption. However, a fuel management capability should be provided to exploit fully whatever latitude the pilot might have in a given mission.

Mechanization of the fuel management capability is not simple. Numerous computations are involved and suitable cockpit displays are not presently available. Thus the problem is twofold: software and hardware. The flight path display alone cannot resolve all of the display hardware deficiencies, but it will represent a significant step forward toward that end. Specifically, two of the three degrees of freedom through which fuel management is accomplished are inherent in the flight path display (i.e., airspeed and altitude). On the other hand, the complete resolution of the software aspects of the fuel management problem is planned as an integral part of the flight path display development.

The flight path display is naturally suited to the presentation of breakaway commands necessitated by a critical fuel state during ACM. A number of alternatives are under consideration, but the exact method of telling the pilot that the breakaway is required because of low fuel has not been completely defined.

2.2.2.2 Energy-Maneuverability Information

The realistic application of energy-maneuverability concepts during ACM is universally regarded as a requirement by the fighter pilot community. Yet, to date, no satisfactory energy-maneuverability displays are available. In the approach we have taken, the application of energy-maneuverability constraints would occur automatically in our "minimum time" mode of fuel management. The energy which the fighter pilot seeks to conserve is his total energy; that is, the sum of his kinetic and potential energies. The former is a function of velocity (i.e., airspeed), and the latter is a function of altitude. Again, these two parameters are inherent in the flight path display.

In the case of the energy-maneuverability display, "where" the information is displayed is just as important as "what" is displayed and "how" it is displayed. If the information is to be useful during ACM, it should be displayed on the head-up display (HUD), since ACM requires the pilot to be "head-up" at all times. The maneuvering flight path display meets all the "what," "how," and "where" requirements of energy-maneuverability. It provides in a HUD each of the required dynamic and attitude information elements in a natural but distinguishable manner.

2.2.2.3 Performance Limits Information

It has been demonstrated in the past that well-trained fighter pilots using existing cockpit displays cannot consistently fly their aircraft to the established performance limits during ACM. Indeed, they are able to realize only seventy-five to eighty percent of the available capability. In other words, today's fighter pilot cannot determine from present instrumentation his exact position within the performance envelope as he maneuvers. Consequently, he cannot accurately assess the proximity of his performance limits. The higher limits are protected by the onset of high acceleration or g loads and are seldom violated. However, one might well wonder how many kills were not logged in the past because of the pilots' reluctance to approach those upper limits. On the other hand, we are all aware of the costly accidents which regularly remind us that the lower limits are easily exceeded.

Aircraft performance envelopes are usually defined as functions of altitude, acceleration, Mach (velocity), and time. Performance limits are often referred to as simply V-N limits (i.e., airspeed or velocity, V, and normal acceleration, N). Again, the maneuvering flight path inherently contains each of the parameters involved in this matter: altitude, airspeed, and normal acceleration. Altitude and airspeed have been discussed previously. Normal acceleration, N, is implicit in each attitude change depicted by the flight path, since each such change involves a related change in acceleration. The flight path is constructed so that aircraft limits are never exceeded. The pilot, by staying on the flight path, is assured that he is operating within limits. During ACM, the flight path will enable the pilot to fly up to the maximum limit of the aircraft if this becomes necessary. The pilot can always exceed the limit if he wishes, since the flight path does not control the aircraft. We think such a pilot option is an indispensable safety feature.

From the discussion thus far, it is clear that the flight path display provides the means for the pilot to exercise precise control of his aircraft during ACM. There is no reason why its capability could not be employed just as effectively in other flight modes. For example, extended flight under instrument conditions should prove to be

significantly easier with the flight path display than with conventional instruments. Indeed, every mode of flight should benefit from the flight path display, both in terms of reduced pilot workload and improved flight control.

2.2.3 Fire Control/Weapon Delivery Information

The common objective of all fire control and weapon delivery systems is to define a trajectory which, if flown, will enable the pilot to hit the target with the weapon involved. The intrinsic value of the flight path lies in its ability to define just such trajectories and to enable pilots of moderate skill levels to fly them effectively. The precise manner in which all elements of the required fire control and weapon delivery information will be presented to the pilot is not fully defined at this time. The final details of this matter, however, will be worked out in the course of defining the scaling and display dynamics requirements for the flight path.

2.2.4 Navigation/Traffic Control Information

The navigation and traffic control information display problems are very similar; therefore, we will discuss them together. Both involve flight around or between specific spatial locations in a specified manner. The most notable differences are the distances and the fuel management modes involved. Navigation involves greater distances and is usually accomplished using a "maximum range" power setting; traffic control involves small holding patterns which are generally flown at "maximum endurance" power. In both cases, all of the information needed by the pilot to fly the required trajectory is inherent in the flight path: heading, altitude, speed, attitude, and end points.

2.3 INFORMATION CONTENT SUMMARY

Now that we have gained some familiarity with the flight path display concept, let us review its information content in comparison with some of today's HUD presentation formats. Figure 5 summarizes this comparison. The most important point to be made from Figure 5 is that the flight path display can provide more information than the conventional HUD formats with significantly less display clutter.

3.0 DEVELOPMENT OF THE MANEUVERING FLIGHT PATH DISPLAY

As we mentioned previously, the concept of a flight path display is not new. However, when we started our study to determine the feasibility of developing an ACM display, we had no preconceived ideas of the matter and resolved only to start with the basic requirements and proceed from there. Accordingly, we planned our study to include in the noted order: the determination of the pilot information requirements for ACM; the definition of ACM display requirements, including the synthesis of the display concept; and the analysis and evaluation of mechanization techniques, including the selection of the most promising approach. Each of these phases of our effort is described briefly in the discussions which follow.

3.1 DETERMINATION OF PILOT INFORMATION REQUIREMENTS

Operational integrity was judged to be a principal requirement for an ACM display. To insure this operational integrity in the hardware, we knew that the basic information requirements had to be operationally sound. We therefore looked to the best source of operational information we could find — the pilots themselves. We spent considerable time discussing pilot information requirements for ACM with a number of operational fighter pilots. Throughout our discussions we emphasized

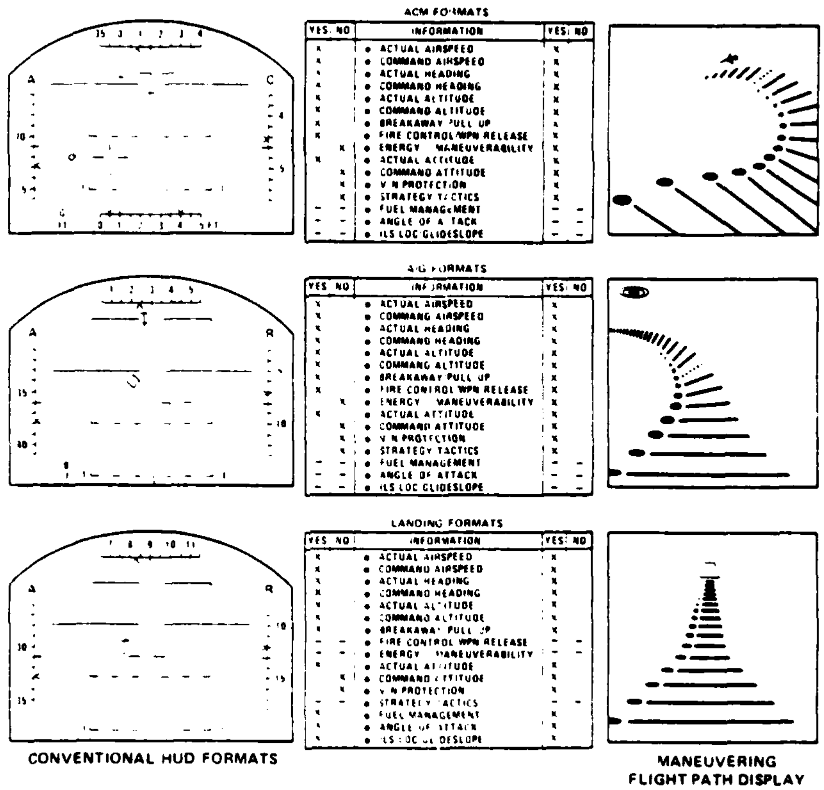


FIGURE 5. COMPARATIVE INFORMATION CONTENT SUMMARY

that we wished to find out only what they needed to know during ACM, without regard for existing systems, hardware, state-of-the-art capabilities, or any other physical constraints. As they stated each of their information requirements, we persisted in finding out why they needed it. With their help we thus probed our way through the problem, and were able to establish what we believe to be the basic pilot information requirements for ACM.

The pilots were asked to define an air-to-air engagement in terms of its phases, identify the objectives of each phase, and describe the information required to achieve the objectives. The results of the interviews are summarized in Figure 6. Significantly, two types of information requirements emerge — the "What Should I Do?" type and the "How Should I Do It?" type. The former relates to the target aircraft and what it is doing. The latter relates to the pilot's own aircraft and how he must fly it.

3.2 DEFINITION OF ACM DISPLAY REQUIREMENTS

The primary objectives of an ACM display are to reduce the pilot workload by presenting "solutions" information, and to decrease pilot reaction time by presenting the information in a readily assimilated format.

The merit of displaying "solutions" instead of "variables" information becomes readily apparent when we consider the number and frequency of judgments which the pilot is required to make during ACM. For example, the "What Should I Do?" information requirements of Figure 6 alone involve 28 conditions which, in their various combinations, result in 2,160 possible engagement states. Even under the most

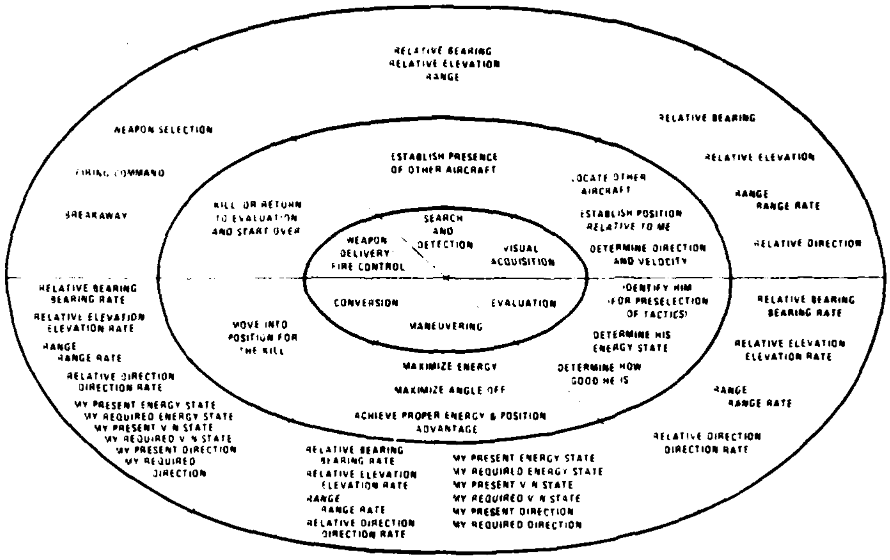


FIGURE 6. THE PHASES. OBJECTIVES AND PILOT INFORMATION REQUIREMENTS OF AIR COMBAT MANEUVERING

favorable circumstances (and excluding completely the "How Should I Do It?" parameters), the pilot cannot read the variables involved and perform the mental integration required to arrive at a discrete solution of his ACM problem. However, this is the type of task at which a computer excels. The obvious approach then is to let the computer perform these tasks for the pilot.

At this point, let us further define what we mean by "solutions" information. Consider for a moment the physical act of flying an airplane. Basically, the pilot controls the vehicle by manipulating the control stick, the rudder pedals, and the throttle(s). These controls are applied in a coordinated manner to produce desired changes in airspeed, altitude, roll, pitch, and yaw. As cockpit instrumentation evolved, it became accepted practice to satisfy these and other pilot information requirements with instruments that were dedicated to the display of single parameters or, as in the case of attitude indicators, a group of related parameters. Generally, the pilot was able to integrate the information from these separate instruments so effectively that he could successfully control his airplane solely by reference to the instruments. The arrangement was simple. The machine provided information on the state of the control variables, and the man provided the "solutions" which enabled him to close the control loop.

As aircraft performance and system capabilities increased, however, the pilot had to deduce the "solutions" in progressively less time while performing successively more system operating functions. The inevitable happened — the pilot began to fall behind his airplane. More to the point, the dynamic capabilities and system complexities which characterize the present generation of fighters virtually prohibit our continuing with this conventional treatment of the cockpit. What must we do to again get the pilot out ahead of his airplane? We must provide a system which continuously correlates all of the variables, makes all of the purely logical decisions, and displays those decisions to the pilot with as much "situation orientation" information as possible. In so doing, we enable the pilot to exercise intelligently and responsively that overall control over the system for which a machine could never be programmed.

The display requirements for ACM must, therefore, reflect the philosophy of presenting all of the purely logical decisions together with an accurate and easily

understood representation of the prevailing situation. All of the system functions involved in a modern fighter aircraft (i.e., tactical control, aircraft performance control, fire control/weapon delivery, and navigation/traffic control) are simply physics problems which lend themselves to relatively straightforward solution by machine. Indeed, in a modern fighter, the sensor and computer elements working together are capable of detecting another aircraft, calculating its relative dynamic state, determining the maneuvers required to engage it under the most favorable conditions, and initiating the necessary initial maneuver before the pilot is able to see the other aircraft. Therefore, we required that our machine solve the physics problems. Displaying the solutions together with an accurate and easily understood representation of the prevailing situation strongly implies a presentation which is analogous to the real world. In the real world situation, the pilot is trying to make good a particular trajectory or flight path relative to his target or targets. This real-world flight path, though invisible, is particularly easy to visualize as a real-world entity since it is visually compatible in every respect with the real world. Thus, we can display a flight path (the logical decisions) in the same presentation in which we display all of the known target aircraft (the prevailing real-world situation), and the tactical implications of the situation will be immediately and easily understood by the pilot. Accordingly, the flight path plus the existing real-world tactical situation meet completely our display requirements for ACM.

3.3 ANALYSIS AND EVALUATION OF MECHANIZATION TECHNIQUES

In the course of reviewing the various ways of mechanizing the maneuvering flight path display, two noteworthy observations were made. First, it became apparent that the problem we faced was primarily a software problem and that, generally speaking, the hardware requirements could be met by any number of presently available head-up displays (HUD's). Second, the application of practical constraints to the multitude of computations involved would serve to make the computations more manageable and feasible for mechanization.

The principal benefits of being able to confine the problem essentially to software is that the development time is significantly shortened and the total costs associated with the display are minimized. A corollary benefit which is sure to have widespread appeal is that existing HUD hardware will not be forced automatically into obsolescence but, with relatively minor modifications, should be able to continue in service.

The application of practical constraints to the computations consists of working out the physics of the flight path during ACM in aircraft coordinates, rather than earth reference coordinates, and in developing a set of realistic engagement rules on which the generation of the flight path display would be based. The merit of working in aircraft coordinates becomes apparent when we realize we are working the ACM problem from the "inside out." In other words, we are observing the tactical situation and determining the related flight path solution in the same context as the entire matter would be seen by the pilot, say through the windscreen. Figure 7 shows the simplified geometry of an engagement as it appears from this viewpoint, in terms of the basic aircraft reference parameters. The obvious advantage of working in aircraft coordinates is the savings in coordinate transformations which it affords. A logical extension of this rationale led to the engagement rules which the flight path uses. Although the use of engagement rules admittedly limits to some extent the validity of the flight path solutions, this is not regarded as a problem. The highly dynamic state of ACM necessitates that the flight path solution be continually updated. This steady flow of solutions produces a convergent situation in which small errors in individual solutions are negligible in the aggregate. The care and understanding with which the engagement rules are postulated can, of course, determine the fidelity

of the flight path. We believe that our flight path display will possess the required fidelity.

In summary, our mechanization of the maneuvering flight path display involves the development of new software which, in the interest of feasibility, reflects the most realistic application of common-sense rules to ACM that we consider to be practicable.

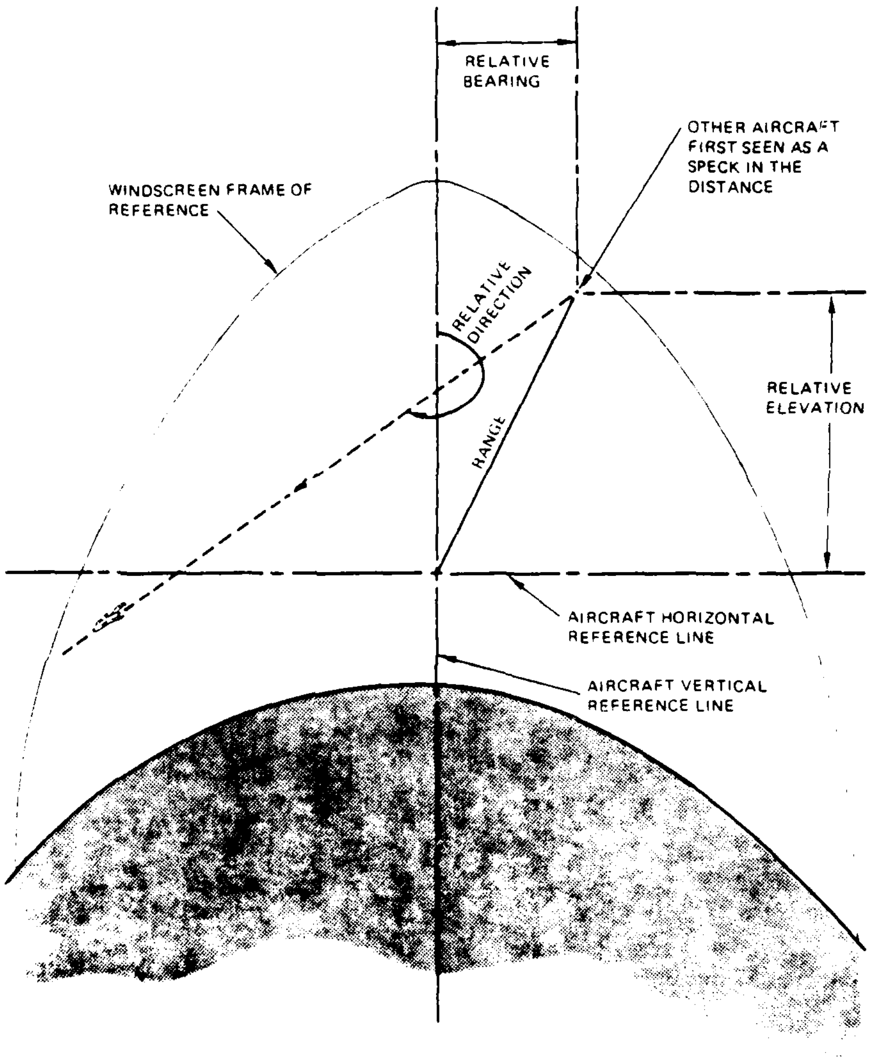


FIGURE 7. "INSIDE-OUT" VISUAL CONTACT

3.4 PROGRESS TO DATE, PRESENT STATUS, AND PLANS

The basic requirements work on the maneuvering flight path display has been completed and development of the flight path software is in progress. This effort is expected to continue through the early part of next year. The intention is to mechanize the fundamental control algorithm first so that the development can move to the simulator as soon as possible. We can thus proceed with the necessary scaling and display dynamics adjustments while development continues on the software required for the various systems functions (e.g., fire control/weapon delivery).

The first phase (which marks our present status) will consist of the development and test of software and hardware. Our second phase, which will parallel the first phase to the extent practicable, will consist of refinement of the system on our fixed-base simulator. The third phase, which will commence only after the system is determined to be functionally sound, will involve verification of system performance on our large amplitude, moving base simulator. In our final phase, we plan to validate the operational suitability of the flight path display in flight through impartial, head-to-head ACM encounters. Barring some unforeseen difficulties, we believe that maneuvering flight path displays can be flying in operational aircraft within two years.

4.0 CONCLUDING REMARKS

This paper has described an advanced display concept known as the Maneuvering Flight Path Display and what we are doing to mechanize it. We believe that the display will prove to be practical and will fulfill all of our expectations for it in terms of system performance, flight safety, and aircrew training. However, we are not suggesting that it will cure all of our cockpit ills. While the flight path display will successfully meet a number of critically important cockpit display requirements, there are many other display needs which it cannot meet. Our ultimate goal is to satisfactorily meet every control/display need in the cockpit. The maneuvering flight path display is our first step toward that end.

RATIONAL STUDY OF AIRCRAFT PILOTING

by
Mr KLOPFSTEIN,
Senior Ordnance
Engineer

RATIONAL STUDY OF AIRCRAFT PILOTING

by

Mr. Klopfstein
Senior Ordnance Engineer

Acquiring the Necessary Data

Aircraft instrumentation is the outcome of a series of breakthroughs made possible primarily by technologic progress in the areas of precision engineering, electronics and more recently EDP. However, no rational study of the data necessary to pilot an aircraft seems to have been made as yet.

Suppose for a moment that there were no birds or flying insects in our world and that the idea of "heavier than air" flying machines was a recent one. What would a team of engineers who had just discovered aerodynamic lift and were designing the first flying machine do to make the machine controllable by an airman?

Before embarking on their research they would try to define the objectives. The principal aim in piloting a flying machine is of course to take it where the airman wishes it to go.

In piloting an aircraft it must be made to follow a desired trajectory. In the light of this definition the airman must be given the

- means of action and

- data

necessary to accomplish his work.

Let us begin with the means of action.

To adjust the trajectory of a moving object a force must be created perpendicular to that trajectory in the direction in which it is to be altered.

Our team of engineers working on the construction of the first flying machine would probably reach the conclusion that for atmospheric flight the best solution is to "guide" and "modulate" the lift force. The first aircraft would therefore have a lift variation control surface, i.e. the elevator and a lift guidance control surface, i.e. the roll control. It would also be equipped with a flow symmetry control surface acting on the side-slip balance, i.e. the rudder.

Probably the solution would not be so very different from our present-day concepts.

For an aircraft flying fairly rapidly without servo-controls it would be difficult to do without the magnificent properties of the lever. And so a "joystick" would be fitted.

Now for the necessary data.

Let us consider again our definition of piloting which consists in causing the aircraft to follow a predetermined trajectory.

The first instrument which springs to mind would be the windscreen (if only by analogy with car driving during the take-off phase).

This instrument might appear useless or even detrimental in some cases: cruising towards the sun, cruising at night, landing with zero visibility and ceiling. Some apparently competent engineers have even tried to build an aircraft without a windscreen. But this instrument is essential (even if it must sometimes be covered) if only because of the extraordinary scenes which can be observed through it. Since the "good shape" of the crew is an important safety factor this instrument must be retained whenever possible.

As the aircraft must be taken where the crew wishes it to go, the first item of data given to the pilot would have been the trajectory. This is the collimated velocity vector.

We all know that a pilot has never been able to obtain this information accurately; it is sufficient to reduce the thrust over a cloud mass and ask "at what point will we enter the clouds?" to realize just how useless the windscreen might seem because it does not give the desired information. Other examples clearly illustrate this shortcoming:

- the aircraft is arriving close to a mountain peak. The altimeter, QNH and temperature, added to the static error of the aircraft, give a better answer than the external world to the question: will we pass over the top (or not at all)?

- the inexperienced pilot who lines up correctly over a runway but is more often than not far too long.

- serious errors in fine weather nighttime approaches detected very late by experienced pilots when operating on special terrain (desert areas, seashore, no glide-path).

Some will say that aviation has managed up to now without this information. Which is of course true, but the main cause of incidents, often without gravity, is landings which are rather short or rather long; in most cases the mistake can be remedied by a burst of acceleration or

vigorous braking unless other aggravating circumstances (high wind gradient, iced runway) turn the incident into an accident.

Out team of engineers would therefore supply trajectory data at the windscreen. The aerodynamic expert would then make the following comment:

"Piloting an aircraft consists in bringing the trajectory to the point at which we are aiming - but we must be in a position to do so..."

This means in effect that the aircraft must fly and continue to fly.

Lift must be ensured and for that to be the case the airflow around the structure must be satisfactory. This condition is achieved, in an incompressible medium, when the angle of attack, i.e. the direction in which the airflow arrives, remains within precise limits. The pilot must therefore know the angle of attack.

What solution has been adopted up to now? The equation for the lift of an aircraft shows that with a given load factor and a clearly defined mass there is a "biunivocal" relationship between angle of attack and the reading of a differential pressure gauge, sometimes known as an anemometer. This equation, for an incompressible medium (at low speeds) is not affected by altitude or temperature.

There was therefore a good substitute for an angle of attack-meter. The pilot had to be careful not to stall in a very tight turn and to add on appropriate extra value to the instrument reading when the aircraft was heavy. But the lowest landing speed, allowing a reasonable margin, is always obtained for a given angle of attack, always the same regardless of the other conditions (altitude, temperature, mass, load factor). With a good angle of attack meter there is no need for an anemometer in the approach phase.

This does not mean that the anemometer should be removed altogether.

When the safety limits are represented by a distribution of pressures which areliable to damage or destroy the aircraft, a differential pressure gauge giving a summary of these pressure values becomes essential. It may also be useful to graduate it in terms of speed for clearly defined pressure and temperature conditions. But this is only a coincidence (although a very useful one...).

When the limits are represented by the appearance of recompression waves (shock waves) which may destroy the pitch balance of the aircraft or dangerously impair the effectiveness of the control surfaces it is essential to measure on obard theparameter which defines the appearance of these discontinuities in airflow. A mach-meter is absolutely essential. In short the choice of necessary data must not be based on routine, empirical observation or the principle of authority but an analysis of the aims to be achieved and the safety conditions which must be observed.

The same reasoning holds good for the power or thrust controls.

A (transport) aircraft will fly almost all the time on a stabilized flight path, i.e.

- practically straight trajectcry

- constant rate turns

- climb and descent observing one or more parameters (angle of attack, slope)

- straight final descent with increase of angle of attack in stages...

- in most of these cases the longitudinal equation shows that the thrust must balance the difference between drag and the component of weight along the trajectory.

The aim of thrust control is therefore to adjust it as function of the difference: drag less component of weight on the trajectory. But for decades engineers have persisted in giving pilots a mistaken idea of thrust in the form of flow values (which are not altogether unsatisfactory...), engine rates, pressure ratios or differences, various temperature values and even surfaces (e.g. position of nozzles when the output section varies). These are all safety parameters: excessive engine speeds may cause the blades to deform or the turbine disc to burst and an excessively high temperature in front of the turbine may give rise to the shame phenomena; a flow rate which is too high may cause an excessive load on the compressor while a set of parameters may give rise to an airflow around a compressor blade which is incompatible with its aerodynamic characteristics (limit of compressibility).

The fact of remaining - with reference to a space of n dimensions - in a given volume representing the correct area of operation of the engine corresponds to the limits encountered when the aircraft is in flight.

But while remaining within these limits it must be possible to adjust the controls as a function of the needs of the aircraft, i.e. the difference between drag and the weight component.

An example will clarify this analysis of the aim: take the case on an aircraft whose pilot wishes to fly level (zero weight component) at constant incidence (i.e. constant speed). The power controls must be adjusted to give a thrust equivalent to the drag.

If the undercarriage is lowered while wishing to maintain the same altitude and speed, the thrust must be increased.

If the aircraft is put into a turn, the increase in drag due to the induced drag must be compensated by an increase in thrust.

To sum up, if a constant altitude and speed are maintained, different thrusts will be needed depending on the particular instance (undercarriage raised or lowered) and on the rate of turn...but the difference thrust less drag must always be zero.

A pilot who has at his disposal a perfect thrust indicator (which is in any case a myth) would therefore have to remember the thrust needed in all cases.

If an indicator displaying "thrust minus drag" is at its disposal, he only needs to remember one figure...zero, for all cases.

To sum up this first section, piloting an aircraft means flying it where the pilot wants it to go - in other words the information required is the trajectory.

For safety reasons, a satisfactory airflow must be maintained around the structure on take-off and landing, in other words the information needed is the angle of attack.

The controls must be adjusted as a function of the difference between the drag and the weight component which must be indicated to the pilot. The safety conditions are obtained by correct control of the "engine parameters". We have of course disregarded here the problems of navigation and range in connection with which flow-meters, gauges and a chronometer are extremely useful.

Definition and Elaboration of Data

Without considering the studies and experiments which led to the results, the basic idea was to present in a simple and intuitive form the two fundamental data items, namely trajectory and angle of attack, with the aid of a single moving reticle. The following simple assumption is used:

"The velocity vector of the aircraft in relation to the mass of air is equal and opposite to that of the air mass in relation to the aircraft..."

In more figurative but perhaps clearer terms:

"The aircraft advances in the atmosphere in the direction from which the air molecules reach it."

If the air molecules arriving from infinity at the pilot's eye (disregarding any deflection) were "red painted" this red point would"

- represent the future position of the aircraft if its flight path is not adjusted (tangent to the trajectory), considering this red point in relation to the landscape, and

- the direction from which the air molecules arrive, considering this red point in relation to the longitudinal axis of the aircraft, i.e. by definition the incidence.

Figure 1 illustrates this principle.

In the three cases the aircraft:

- is in a correct descent plane (3^{o} for example)

- has its trajectory oriented in the descent plane (to reach beginning of the runway) so that in all these cases the trajectory reference is located as the beginning of the runway which itself is situated 3^{o} below the horizon line.

The three images of the outside world a, b, and c are therefore identical. If the aircraft were removed the 3 images would be the same.

On the other hand, in case a, the aircraft is moving too slowly and is at too steep an angle. The runway and trajectory reference are very low in the windscreen.

In example b, everything is correct while in case c the aircraft is flying too quickly, its angle of attack is too low and the whole image is at the top of the windscreen.

If therefore, wer represent, e.g. by a cross, a direction which is fixed in relation to the aircraft, representing geometrically the correct approach angle of attack a (with reasonable safety margin) the moving reticle (red dots) and fixed cross together give the 2 necessary data items:

- trajectory

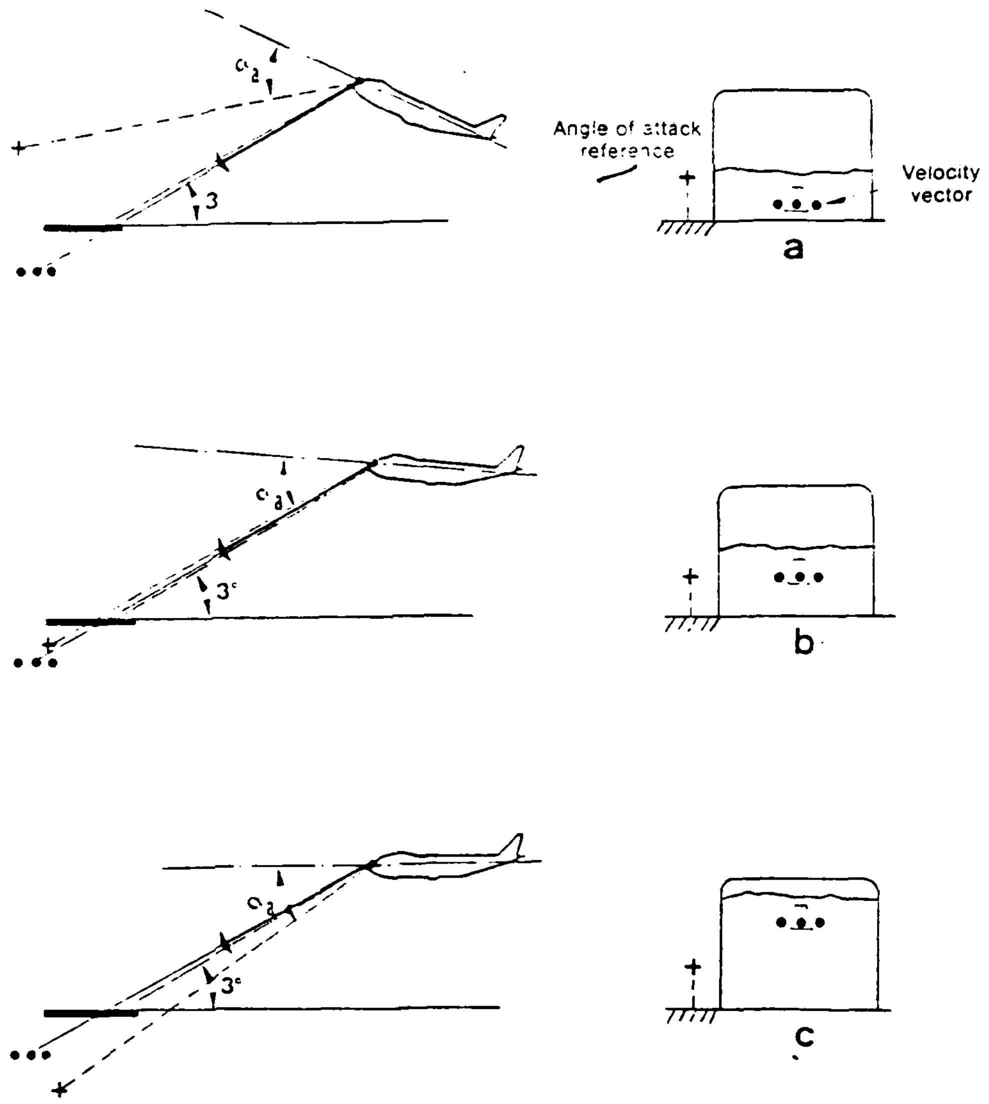
- incidence

The red dots, observed in relation to the "outside world" show the future touch down point.

If they are below the fixed cross, the air molecules are arriving from too low a point and the incidence is too high.

If they are above, the incidence is too low. When they coincide the airflow is correct with a certifiable margin at the lowest landing speed.

To actuate this reticle only a simple angle of attack probe is needed. Without going into detail, it is sufficient to note that the measurement of angle of attack on an aircraft is at least as simple and reliable as the measurement of static pressure and is even theoretically



α_a
3
Angle of attack reference
Velocity vector
a
α_a
3°
b
α_a
3°
c

FIGURE 1

less sensitive to the position at which the probe is installed.

The relationship between the local incidence measured by the probe (at practically any point on the aircraft) and the fuselage incidence is linear for a given configuration and mach number. The only drawback lies in the fact that if the system is to be extended to all aircraft situations the lay must be corrected as a function of themach number.

Once this law has been established, it is sufficient to position a reticle on the fuselage incidence at scale 1.

This is essential as a change of scale would cause the trajectory information to be lost. The information needed to control the engines is easily obtained by measuring on board the aircraft the "reduced variation of the total height." If an aircraft is at the altitude z its potential energy is mg z. Its kinetic energy at the speed V is $1/2\ mV^2$

Total energy is the sum :

$$E = mg\,z + 1/2\ mV^2$$

The quantity $\frac{E}{mg} = z + \frac{V^2}{2g}$ is homogenous at a height, it is known as the total height H.

This means that an aircraft flying at an altitude of 1000 m at 200 m/s can theoretically climb in a glide to

$$1000 + \frac{(200)^2}{2 \times 9.81} = 1000 + 2000 = 3000 \text{ m}$$

The derivative of total height is :

$$H' = z' + \frac{V.V'}{g}$$

We divide by the speed value to obtain a dimensionless number. The reduced derivative is therefore :

$$\frac{H'}{V} = \frac{z'}{V} + \frac{V'}{g}$$

The first term $\frac{z'}{V}$ represents the sine of the slope

The second term $\frac{V'}{g}$ represents the acceleration on the trajectory expressed in units " g ".

This quantity $\frac{H'}{V}$, the reduced variation in total height, is known as total slope or sometimes, less correctly, as the potential slope.

This relationship signifies quite simple that the reduced variation in total energy is represented by the sum of the slope (representing the reduced derivative of potential energy) and the acceleration on the trajectory (representing the reduced derivative of kinetic energy).

In fact when the slope is positive the aircraft climbs, so that its potential energy increases and vice versa.

When it accelerates on its trajectory its speed increases so that its kinetic energy increases and vice versa.

From the general equation of flight :

$T - Rx - mg \sin \gamma = m\Gamma$

Where T = thrust, Rx = drag, γ = slope and Γ = acceleration on the trajectory, we obtain :

$$\frac{T - Rx}{mg} = \sin \gamma + \frac{\Gamma}{g}$$

$$= \frac{\dot{z}}{V} + \frac{\dot{V}}{g} = \frac{\dot{H}}{V}$$

$$\frac{T - Rx}{mg} = \frac{\dot{H}}{V}$$

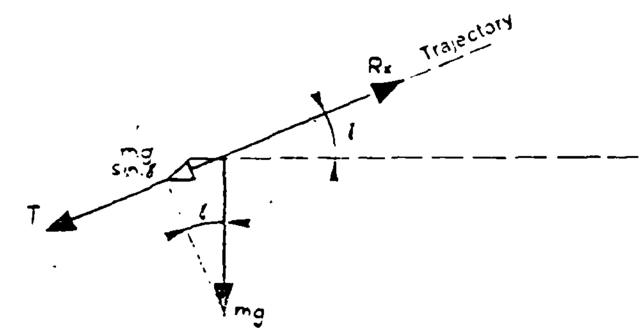


FIGURE 2

The total slope is therefore an expression of the excess (or deficiency) of thrust over drag. The value $\sin \gamma + \frac{\Gamma}{g}$ can be measured by an accelerometer permanently fixed according to the trajectory for which a gross indication would be obtained (without correction for gravity to retain the term $\sin \gamma$).

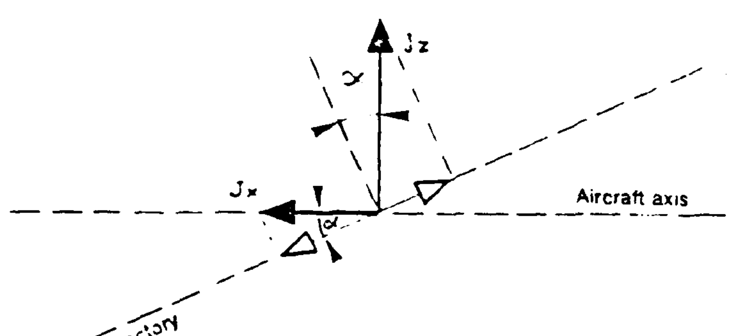


FIGURE 3

For greater simplicity preference is generally given to two fixed accelerometers secured according to the axis of the aircraft and the perpendicular axis located in the plane of symetry of the aircraft. Their gross indications (without correction for gravity) Jx and Jz are introduced into a small computer to give the value Jx cos α − Jz sin α (α = fuselage angle of attack) which represents the projection of these accelerations into the trajectory, i.e. as previously, the value $\sin \gamma + \frac{\Gamma}{g} = \frac{\dot{H}}{V}$

If we add to the velocity vector at the windscreen, which is in fact a slope indicators, a reticle giving total slope, the distance between the second reticle and the first gives an intuitive image of acceleration on the trajectory. See figures 4 and 5

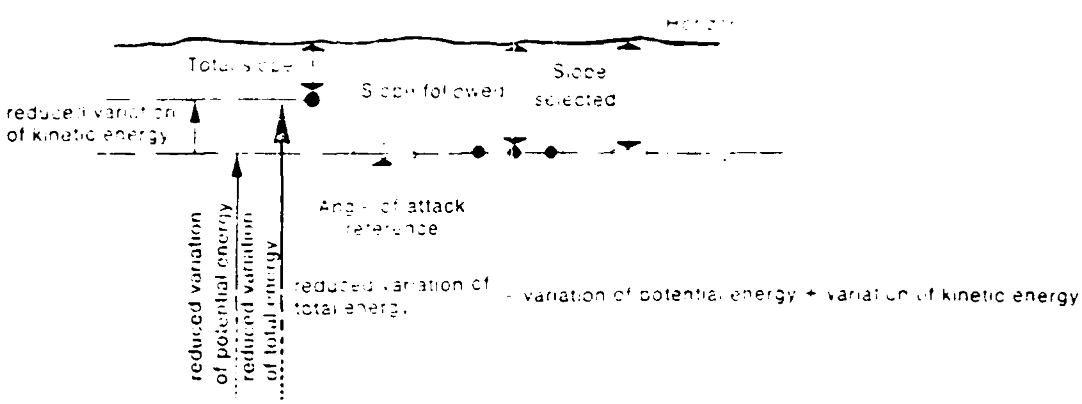


FIGURE 4

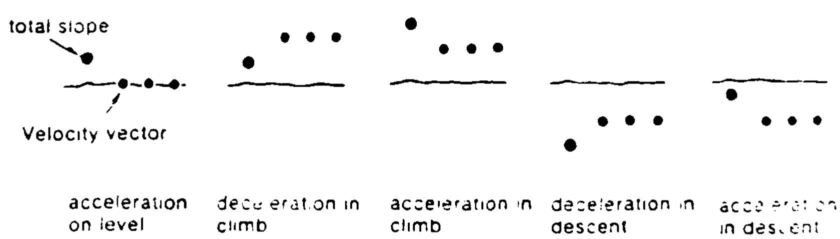


FIGURE 5

When the reticle representing the total slope is above the three red points representing the velocity vector the thrust is too great to balance the flight ; the aircraft accelerates. When it is below the three red points, thrust is insufficient : the aircraft decelerates.

The total slope reticle can be controlled with the thrust lever (term T). It can of course be influenced by any variation in drag (lowering the undercarriage, changing the speed or configuration etc. : term Rx) but this is an ADVANTAGE.
This system is infinitely better than the " fast-slow " indicators which are sometimes installed as it indicates a variation in angle of attack which will take place and not a small difference.
A correction must of course be introduced by stating :
acceleration = reduction of angle of attack in stabilized trajectory ;
deceleration = increase in angle of attack – but this is extremely easy to grow used to.

This system is ultimately very simple and consequently both reliable and inexpensive. One single drawback results from the fact that the " total slope " reticle must be positioned from the horizon. The vertical error is therefore introduced (which is not the case with the velocity vector).

USE OF THE INFORMATION – ACCURACY OBTAINED

The use of the trajectory reference is self-evident. A theoretical study shows that the pilotability of the reticle using the depth control is very close to that of the aircraft attitude (turbulence being filtered out in relation to the aircraft axis).

The accuracy achieved is in the order of a tenth of a degree in a calm atmosphere and of half a degree in average turbulence. It depends of course on the type of aircraft. Random errors in the order of half a degree have no influence whatever on the trajectory obtained as their mean value is zero and the trajectory is the " integral " of speed, in other words in essence an average. A systematic error is caused by the wind which means that the ground trajectory is not the same as the air trajectory.

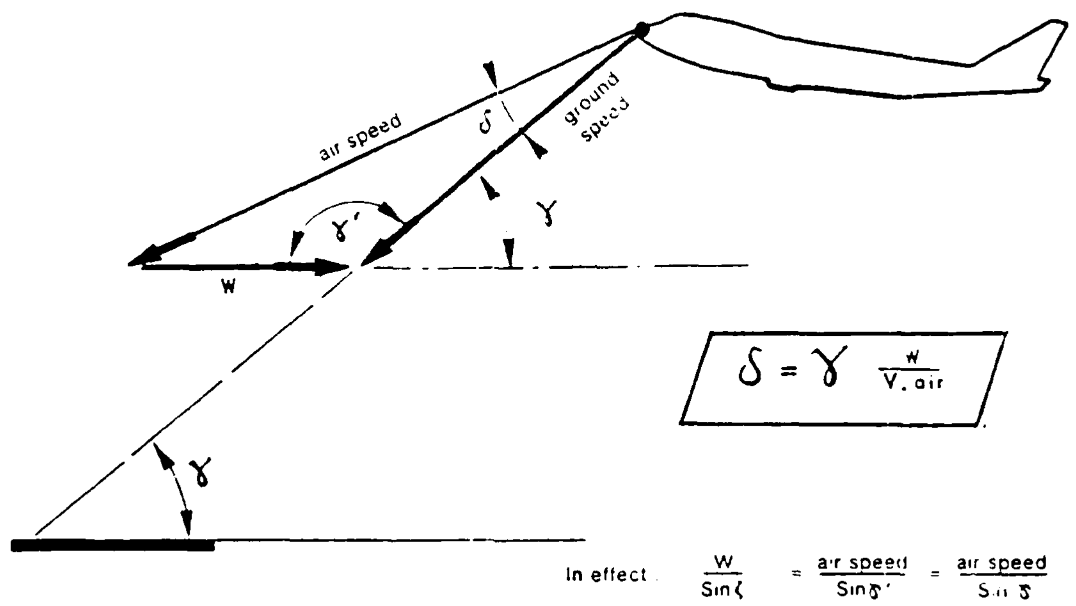
The wind introduces a vertical drift which means that if we aim at a point on a runway with the air velocity vector, this point will be reached by describing a kind of " dog-leg " curve approximating very closely to a straight line. The deflection of this dog-leg curve is very slight since the flight path (in effect the descent plane) form a very low angle with the wind. Close to the ground the wind is always horizontal and the descent plane is at most 3 or 4 degrees from the horizontal so that drift is therefore very slight.

The visual impression of " deepening " is, however, considerable : when the pilot is 10 feet below the descent plane at 200 metres from the point aimed at on the runway the line of sight forms an angle from the horizontal of close on 30 % less than the normal descent angle. The impression of flattening is therefore very great in the final approach phase although the position is only very slightly below the theoretical descent plane.

Since this drift is easy to correct, it is perhaps more logical to introduce a correction obtained by a simple formula – figure 6.

$$\text{correction} = \text{selected descent plane} \times \frac{\text{wind speed}}{\text{aircraft speed}}$$

FIGURE 6



This correction can easily be introduced into the reticle of the visual guidance system (head up display).

It would of course be possible to indicate the ground trajectory but this data would require a complex – i.e. expensive and unreliable – method of determination and would also not enable
- angle of attack
- flare-out and touch down point to be shown.

In all cases the correction must be disregarded in a short final approach ; the curvature is then imperceptible if we start out from the correct descent plane.

Use of the angle of attack information and of the total energy indication is extremely simple : on a given slope the total index must be above the trajectory (acceleration) if the angle of attack is too great and below it otherwise. When the angle of attack is correct it is positioned with the thrust levers opposite the velocity vector.

The total energy derived index may be said to " draw in " the velocity vector in the axes linked to the aircraft.

When the thrust can no longer be controlled (engine failure in a climb for example) the trajectory slope is of course adjusted to accelerate the aircraft if the angle of attack is too high.

When the angle of attack is correct, the total energy variation reference shows the maximum slope on the residual thrust.

Under normal conditions the rule for piloting is as follows :
- display of trajectory reticle on a ground point or slope reference
- modulation of thrust with the aid of the energy index to ensure correct angle of attack

Under normal conditions :
trajectory, incidence, total energy.

In the event of engine failure :
- determination of optimum angle of attack by influencing the trajectory in relation to the energy index
- action on trajectory to display maximum climb angle.

The pitch attitude is no longer piloted ; this is unnecessary
- as the piloting aims defined above do not require it and
- because it will in reality be better piloted because it represents the sum of trajectory slope and angle of attack.

The latter relationship shows that the attitude information created an unnecessary redundancy which complicated the pilot's task.

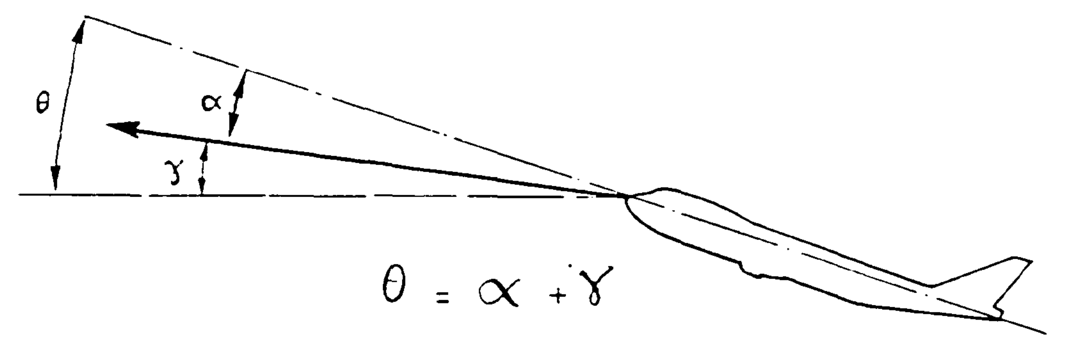


FIGURE 7

Since in fact the attitude θ is equal to the slope γ plus α, it is clearly impossible to " display " a priori an attitude and an indicated air speed, i.e. an angle of attack and to obtain at the same time a suitable slope γ since the slope will result from the value for θ and α.

However, γ is an objective and α a safety condition ; it is therefore only possible to eliminate θ. Of course very good vertical references are needed in an aircraft to measure, with the velocity vector, the trajectory slope. As the velocity vector is obtained to 1/10 th of a degree, progress must clearly still be made (excluding inertia) in vertical gyros.

Flare-out and impact become very methodical operations : the final phase of landing consists of adjusting the trajectory to obtain a slope giving a vertical speed compatible with the limits of the aircraft structure and the comfort of the passengers

This slope is 0.6 to 1° for most aircraft.

At a given altitude it is therefore sufficient to display this slope, hold it and reach the ground.

This manoeuvre bears no relation to the method recommended by certain aerobatic pilots who claim to be able to display an attitude and reach the ground. They forget that 3 to 5 knots less than the habitual indication could result in an incidence 1° higher (at the same attitude) and therefore to a 1° higher trajectory slope. Ultimately this means a vertical impact speed which is twice as high. In fact these pilots do not maintain the pitch but unconsciously impart a slight curve to it before the ground.

The air velocity vector is of very great interest in a wind gradient. The consistency of the " aim " causes the pilot to curve the air trajectory slightly without realizing it, thus precisely correcting the loss due to the gradient. If the pilot follows his safety parameter, namely the angle of attack (which is immediately visible since the same reticle is used), he will at the same time observe an increase angle of attack which will be corrected easily by immediate action to adjust the thrust.

It is interesting to note that no special procedure is required. A slope reference using a specific elevation angle in relation to the horizon is an essential addition to the information described.
Figures 8 and 9 give examples of uses.

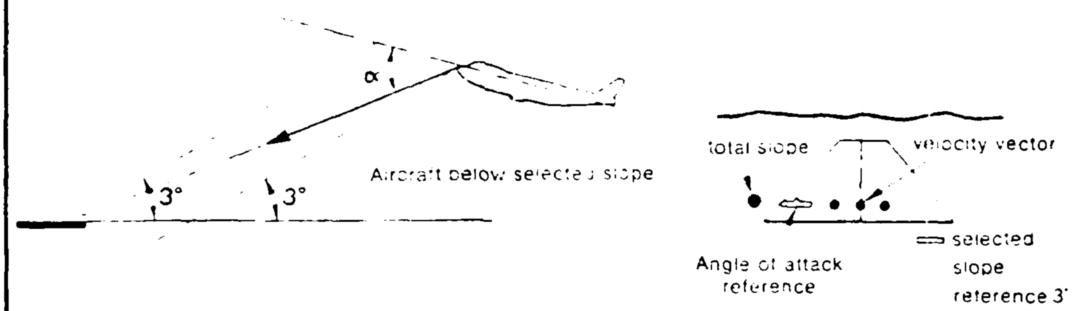


FIGURE 8

In figure 8 the aircraft is in a balanced descent at the correct angle of attack but below the selected descent plane.

As the velocity vector is above the slope reference, the slope is lower than the normal value. The runway threshold therefore appears above the slope reference.

In figure 9 the aircraft is stabilized above the selected descent plane.

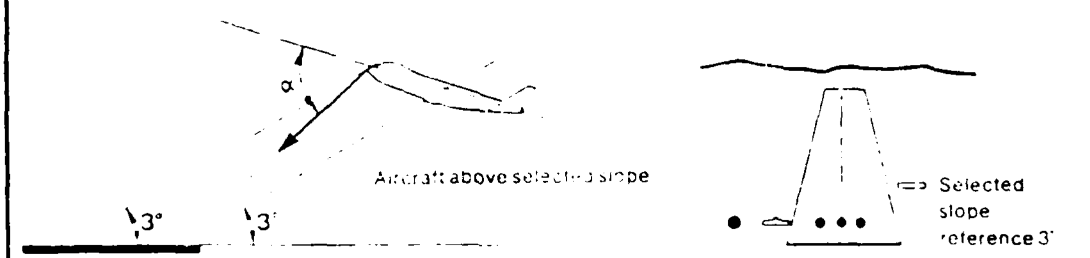


FIGURE 9

DETAILS OF TESTS CARRIED OUT

The first experiment was conducted on a simulator using an electro-mechanical head up display (CSF 200) representing a runway. This head up display had flown without the velocity vector and the coincidence between the real and synthetic runways had been obtained in flight. On the simulator the velocity vector enabled impact to be reached using collimator alone.

The first in-flight test was carried out using a crudely made collimator with a lens of no more than 45 mm. The aircraft was a Mirage III B with variable stability which unfortunately can only be landed by the forward pilot under "emergency" conditions (single chain electrical piloting).

Approaches up to 150 feet showed a considerable improvement in piloting accuracy. The anemometric deviations and trim deviations were reduced in a ratio of 3 to 4, these two parameters no longer being piloted. This was in 1968.

These results enable us to design a simplified collimator (moving diamond, fixed line) of good quality which was mounted on a standard Mirage III B. The aircraft could then be landed by the pilot using the collimator.

Official experiments conducted by the French Flight Testing Centre (Centre d'Essais en Vol) followed the author's initial trials. They enable some thirty pilots to effect more than four hundred landings, including 30 at night, under conditions of repeatability never obtained hitherto : pilots who had familiarized themselves with this new system touched down on the runway with anemometric deviations of a few knots, a longitudinal dispersion in the order of one hundred metres and a vertical speed dispersion on impact never before achieved.

In the light of these first experiments : the French fleet air arm decided to modify its carrier-borne fighters.

In 1969 the first airline pilots became acquainted with the system. As a result of these information flights the OCV expressed the hope that the trials on commercial aircraft would continue.

The first simply built head up display was then mounted on the Nord 262 operated by the Ecole Nationale Supérieure de l'Aéronautique and contacts were made with the air traffic management of Air France.

These contacts enabled the development department to begin experiments with the speed vector, using an extrapolation of existing commercial equipment which was in fact not very suitable for this configuration (see next section).

But the author wishes to remind readers that there was no alternative at the time. And it was through the interest shown by Air France in these studies that he was able to obtain the credits to build two experimental units with completely new technology, perfectly adapted to the presentation of this data and representing in fact the prototypes of head up displays with the velocity vector and total energy which should be in commercial operation within a few years.

Incidentally an experiment was conducted by UTA with a view to comparing an Americain system using an approximation to the ground trajectory and a French unit based on the air velocity vector and total energy.

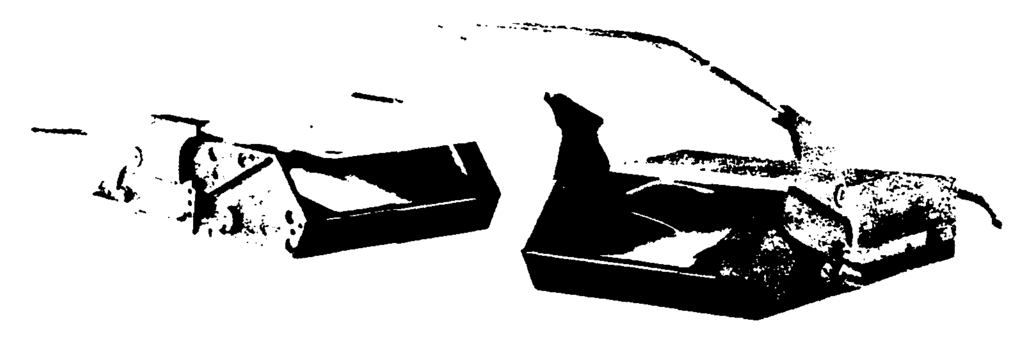
The total energy variometer has been flying for more than a year on the ENSA Nord 262 ; the ease of interpreting the information obtained has gained the unanimous approval of all civilian and military pilots who have used the system.

The two prototypes of the head up display referred to above consist :
– on the one hand of a small-sized VMC head up display comprising only the velocity vector (and incidence) and total energy. The technology is highly reliable and simple.
– on the other of an " all weather " unit with a cathode ray tube which also represents a collimated runway.

The pre-industrial version of the first head up display is now being tested. The second has given results exceeding the most optimistic forecasts ; the Nord 262 can be lanced by the pilot under heavy cloud cover in conditions under which no automatic system can be envisaged for the same function today. Many landings have been made with following winds of more than 30 knots under turbulence too high for an auto-pilot to be switched in under gyroscopic surveillance alone.

This head up display has been flying since April 1971 and the first landing under heavy cloud cover was effected on the fourth flight.

In July 1973 this system, although still in the state of a laboratory model, flew more than 500 hours practically without trouble. More than 700 landings under heavy cloud cover have been made, including 75 under real CAT III conditions.



Display of the visual Guidance System " CV 91 AB " developped by Thomson-CSF

More than 30 % of these landings were made by airline pilots after one hour's briefing and three-quarter of an hour's habituation to this type of piloting.

This experiment conducted with a majority of Air France and UTA pilots is certainly unique in the annals of the aircraft intrumentation as it was completed less than nine months after the first flight.

HEAD UP DISPLAY ERGONOMICS

A few areas of reticence must still be overcome. They are inevitable but very few. They are certainly due to the fact that hitherto " head-up display " consisted essentially in overloading the windscreen with instrument panel data, i.e., dials, scales, indexes, digits etc.

There were two kinds of drawback to this :
– this data was not related to the outside world. For example if a digit 60 was superimposed on the top of the control tower it did not mean that the tower was sixty feet high – the pilot might read a height of 60 feet opposite a reference point but then he could no longer " see " the control tower. The windscreen had been " eliminated " (see above).

– this data was linked to the aircraft, for example a heading scale was always situated at the same point in the head up display field. When the pilot read his heading, his line of sight was fixed in relation to references linked to the aircraft. However, the whole oculo-motor system of the human eye is designed for this " detector " to remain fixed on any given object despite the movement of the body and head. Under turbulent conditions it is therefore preferable to look " outside " than to read a book held in the hands, an instrument panel or an inadequate head up display.

The velocity vector and synthetic runway are typical items of information suitable for superimposition on the outside world in the windscreen ; the two drawbacks referred to above then disappear.

CONCLUSIONS

The author wishes to thank the Operations Directorate which has enabled him to outline his views here.

I should like to take this opportunity to request users neither to approve nor reject outright these fundamental ideas. A period of habituation is necessary and it must be completed before a judgement is passed.

One condition must be met if the judgement is to be valid : the data presented must be used honestly ; in other words the pilot must not simply observe the new data while still flying as he did before.

This procedure could in any case be dangerous.

It should also be stressed that the methods of piloting described above in no way influence the arguments as to the relative merits of manual and automatic piloting.

For auto-pilot systems the methods described provide above all immediate overall control data more directly assimilable than that obtained with existing position instruments which require a synthesis to be made.

It is also evident that in a transitional period during which the airlines will be effecting retro-fits on existing aircraft, a number of inevitable imperfections will have to be accepted. Ideally the new principles should be introduced when the cabin is designed.

Despite initial defects an effort must be made to adopt these ideas as the tests conducted so far have shown that they result in greater control of the aircraft.

The latter point is not only an important safety factor but also perhaps for many pilots one of the attractions of the profession.

WIDE FIELD OF VIEW HUD USING DIFFRACTION OPTICS

R. A. Lohmann

A. A. Berg

Hughes Aircraft Company

Culver City, California

Advances in the state of the art of Diffraction Optics make possible the development of wide-field-of-view Head-up Displays (HUDs) suitable for advanced aircraft applications. Diffraction Optical Elements are lenses and mirrors produced in a thin substrate by a "holographic recording" process. These elements have unique properties which make them extremely useful in this type of aircraft display applications.

The HUD has become a primary pilot display for presentation of essential flight information, fire control and/or weapon delivery information. Presently available HUDs are limited in a) fields of view relative to pilot need and b) reliability, resulting in relatively high maintenance requirements. The development of advanced aircraft with increased maneuverability combined with high angles of attack and of weapons with increased off-boresighr capability results in a greater need for a HUD with a larger field of view. The aircraft canopy and ejection clearance generally provides a limit to the vertical field of view. This is primarily the angle between over-the-nose line to the canopy clearance forward of the ejection line above the instrument cowl. The azimuth field of view is limited primarily by the space which can be allocated to the HUD's projection optics. The field of view requirement for various aircraft operational modes are summarized.

The maintenance requirements of present HUDs are largely dependent on the CRT and its High Voltage Power Supply life and failure rate. This is due in large part to the need for extremely high beam currents to meet the visibility requirements in the high ambient light background against which the HUD must operate and the low efficiency of the conventional combiner.

With Diffraction Optics, Head-up Displays can be designed with larger fields of view, improved see-through characteristics, and with brightness and viewability 2-3 times present HUDs. This provides significant operational benefit in both greater off-boresight capabilities and a more viewable display. These displays can be designed for current aircraft systems and for advanced aircraft where a system such as AIMIS would be utilized.

The Diffraction Optics lens is utilized for the combiner of this HUD. In this application, the optical element is essentially a mirror with optical power. The diffraction lens provides increased light reflection efficiency, in excess of 80% where a conventional combiner will typically have a 25% image reflection efficiency. Thus, the diffraction optics lens can reduce the demand for light output from the CRT for equivalent viewability to a third that of a conventional HUD. This will result in significantly increasing the CRT and HVPS life and reducing the HUD failure rate drastically.

Hughes diffraction optics development for HUDs has been supported by a USN NADC/NASC program which has developed the basic technology for design and fabrication of large diffraction optical elements of up to 16 inch diameter. Additionally, a visor display development for the AF AMRL laboratory proved the feasibility of lenses on curved surfaces operating with a CRT image source.

Presently, Hughes is fabricating a HUD optics unit with an instantaneous field of view of 35° horizontal and 20° vertical. Other characteristics are similar to conventional HUDs. This unit, which will be flight tested in 1977 will demonstrate the performance characteristics described.

The diffraction optics combiner shows promise of increasing the field of view by a factor of 2 horizontally and 1-1/2 to 2 times vertically, depending on aircraft configuration. Display viewability will increase 2 to 3 times while CRT life can increase through lower drive requirements. This will result in a significant reduction in life cycle cost for the HUD. Manufacturing costs are expected to be similar to conventional HUDs. Applications for the future are expected to incorporate diffraction optics lenses in the aircraft canopy which will provide new possibilities for information display and off-axis information and target tracking, and system utilization.

HOLOGRAPHIC DISPLAYS - A REVIEW

DR. S. BENTON

HOLOGRAPHIC DISPLAYS - A REVIEW

Stephen A. Benton
Research Laboratories, Polaroid Corporation
750 Main Street, Cambridge, Massachusetts 02139

ABSTRACT

Holography has produced many spectacular displays for educational, commercial, scientific and artistic purposes; but it must continue to advance technically and esthetically to establish itself as an impressive and versatile medium. Here we examine the status of holography as an imaging medium, and some prospects for larger, brighter, clearer, deeper, and more colorful displays. The properties of available photosensitive materials and light sources, and reasonable costs, impose a structure of compromises on practical imaging.

INTRODUCTION

About ten years ago the imaging community was swept by the news of three-dimensional laser photography at the University of Michigan.[1] The popular media confidently predicted that we would soon be watching three-dimensional wall-sized television, and reading three-dimensional books and billboards, after a few technical details had been ironed out. As the articles in this issue point out, other applications of holography have come to be more important, and commercial interest in visual displays has dwindled after an early burst of enthusiasm. With the closing of the country's largest holographic display facilities at McDonnell Douglas Electronics Corp. (nee Conductron), the medium has been left in the hands of a relatively few energetic holographic "visionaires" who are working generally with meager resources to overcome the obstacles that display holography has found.

This is not to say that holography has failed to have an impact as a display medium! On the contrary, many remarkable displays have been created and widely exhibited with good response.[2] Hundreds of thousands of holograms were published, notably by the World Book Encyclopedia, and holographic finger-rings were even test marketed as breakfast food premiums. Large custom holograms have been created as commercial[3] and educational exhibits,[4,5] probably the most well-known being the venerable Fisher Body display in the General Motors Building, New York City. Holographic portraiture was offered, with Prof. Gabor an early subject, and holography caught the interest of artists such as Naumann, Indiana, and Dali, whose works have been exhibited in well-publicized shows.[6] However, these holograms were created largely with techniques established well before 1970, and many of the limitations of the medium have not been overcome as quickly as expected. The images have remained dim, monochromatic, speckley, and expensive. More recent

developments are proceeding on a much reduced scale to work around some of these problems, exploiting properties of holograms that are unique to display applications.

TYPES OF HOLOGRAPHIC DISPLAYS

As the introduction suggests, this review will be limited to a fairly narrow class of displays, in which a hologram is used to store and present to an observer a three-dimensional image. This image might be of interest for an educational, commercial, medical diagnostic, or other reasons, but its distinguishing feature is its remarkable depth and parallax without viewing aids and viewing location restrictions. Holograms play roles in other types of displays, for example as exotic optical elements in a helmet-mounted display,[7] as convenient stores of full-color two-dimensional moving-map images,[8] and in a proposed screen for autostereoscopic cinemas,[9] but these are beyond the present scope. We begin with a review of the types of hologram images that are of interest in display applications.

TYPES OF HOLOGRAPHIC IMAGES

First-Generation Holograms

A first-generation hologram as ordinarily viewed (looked through as a window) presents the highly realistic orthoscopic virtual image behind the plate, in the location of the original subject. This is the "textbook" hologram experience and has been adapted for display in many ways, such as in 360° cylindrical holograms.[10] The same hologram can be illuminated from a different direction (or turned over) to present the conjugate image, generally a real image that is magnified and distorted, and has the mirror-reversed spatial structure and paradoxical "outside-in" property that has earned it the description "pseudoscopic." An image hanging in space, in front of a plate, has undeniable popular appeal ("you can almost touch it!"), and the conflict of depth cues in a pseudoscopic image is usually resolved as an apparent rotation of the image as the viewer moves, sometimes a desirable "interactive involvement."

Second-Generation Holograms

By properly illuminating a hologram, it is possible to project an undistorted real image, and to make a "second-generation" hologram within that projection, so that the image as eventually viewed can come up to and through the hologram, into the viewer's space.[11] Because the image can be undistorted and orthoscopic, this technique is capable of a wide range of realistic effects, and is a prominent display format. Lenses and mirrors can be used instead of the first hologram,[12] but the two-step technique is well-suited for multiple copying, and the two holograms can be separately optimized for their roles. For ideal

imaging, collimator-type optics as large as the holograms are required. An important feature of the process is the ability to minimize the image depth-of-field by straddling the hologram plane, which allows reduced coherence of the reconstructing illumination and brighter images. The range of allowed viewing directions can also be carefully tailored, allowing an additional "directional gain" of image brightness.

Projected-Image Displays

Holograms can be combined with lenses, mirrors, and other carefully-designed optics to project images that are much larger than the hologram, though at a cost of permitted viewing angle[13] or resolution[14] dictated by conservation of the space-bandwidth product (Lagrange invariant). The concommitant "brightness theorem" limits the luminance of the images to those of directly viewed holograms of the same size.

Horizontal-Parallax-Only Holograms

We have alluded to the fact that a reduction of the amount of information that a hologram must reproduce (i.e. reduced depth of field) can lead to corresponding relaxations of constraints on the display (i.e. reduced source coherence). This relationship can be further exploited in ways that are unique to holograms intended for visual display. For example, because the eyes are separated horizontally to capture slightly differing perspectives, and because viewers generally move across a horizontal surface to enjoy motion parallax, very little of the viewing experience is lost by completely eliminating the variation of perspective with vertical motion.[15,16]

Horizontal-parallax-only images are designed to be viewed from a particular distance, and if the observer moves forward or back, an inherent height-to-width distortion occurs that increases with depth from a "stigmatic image surface" (wide ray bundles from image points at other depths are astigmatic), often the hologram plane. A modest amount of distortion is acceptable, so that workable compromises of viewing distance and image depth can exploit the fruits of information reduction. One scheme permits transmission holograms to be illuminated with common white-light sources to produce deep, sharp, very bright images.[17] Many further implications of horizontal-parallax-only imaging remain to be explored.

TYPES OF HOLOGRAMS

All of the above image types can be produced by holograms in the transmission or reflection mode, and both of these can be either thin or thick (volume), absorbing or non-absorbing (phase, dielectric) holograms. The properties of the various combinations have been discussed elsewhere,[18,19] and will be referred to in later sections. Photosensitive materials for holography have also been discussed,[20] and we limit ourselves here to a few of particular interest.

Most prominent are the silver halide based materials; their high sensitivity, wide spectral response, wide range of types, and reliability have earned them the sobriquet of "the holographer's only friend." They are readily bleached to produce volume dielectric images,[21] and new recipes for producing bright, haze-free holograms that do not darken are circulated widely; their physical and chemical actions are often obscure. Materials such as dichromated gelatin[22] and, more recently, photopolymers[23] have emerged as challengers, without the shrinkage problems and higher noise levels of present silver halide systems, but their much lower sensitivity is a serious impediment to their wider use.

ADVANCES IN DISPLAY HOLOGRAPHY

As remarkable as our laboratory images of locomotive engines and chessmen are, one need encounter only a single designer who wants to see that "seven-foot ketchup bottle floating in the aisle" to realize how far holography is from the hopes of commercial graphics. It seems that one can indeed do almost anything by means of a hologram, until a reasonable bright image is required. If, in addition, non-laser illumination is necessary, the holographer soon finds himself in a fairly small multi-dimensional box, within which he must find the various compromises for a useful display. We will explore this box by examining some of the technical implications of questions that often arise when people look at holographic displays. Space limits us to a general representation of the state-of-the-art, so that many of the "buts" and ingenious solutions provided by holographers must be omitted.

"Can You Make It Brighter?"

Hologram images for display applications must be much brighter than those we now see in dimly lit rooms with blackened walls. A display combines a hologram, an illumination source and optics designed together to produce the desired image. Because the image luminance is simply related to the product of the hologram diffraction efficiency and the illumination irradiance, we begin by examining them separately in a simple context.

In order to attain high diffraction efficiencies, display holograms are generally of the volume dielectric type. Although they are capable of a diffraction efficiency of 100% in theory, in practice the limit is determined by the onset of diffuse scattering into the image, due mostly to "intermodulation noise" (Ref. 24 considers practical tradeoffs for the same problem in thin phase holograms). Materials differ widely in diffraction efficiency vs image contrast characteristics depending on linearity of response, low- vs high-spatial-frequency response, and processing technique[25]. A luminance ratio of 50:1 at a light-dark edge would be comparable to a good reflection photograph ($\Delta D \approx 1.7$), and a diffraction efficiency of 28% at this contrast with bleached silver halide material is quite respectable,[26] although twice that should be attainable. Thicker materials with little response to low spatial frequencies, such as photopolymers, hold out hope for even lower intermodulation noise levels.

The luminous flux diffracted by a small area of a hologram is distributed over the entire image, and the larger the image angular subtense or, equivalently, the viewing zone solid angle, the lower will its luminance be. The solid angle is often limited by the size of optical elements and the overlap of "zero-order halo" to about 0.55 steradians ($\approx$ 30° x 60°), though it may be much less, especially vertically. In order to be easily visible in room light, extended "white" areas should have a luminance of about 70 nits (20 foot-lamberts). The scene-averaged luminance might then be about 14 nits, although the amount of highlight or "black" areas can affect this greatly. Therefore, the hologram must diffract an average flux density of

$$M_1 \approx 14 \times 0.55 = 7.7 \text{ lux} \quad (1)$$

$$M_e \approx 48 \text{ mW/m}^2 \text{ @ } 633 \text{ nm} \quad (2a)$$

$$\approx 11 \text{ mW/m}^2 \text{ @ } 550 \text{ nm} \quad (2b)$$

If the diffraction efficiency is 20%, then the illuminance/irradiance in the hologram plane must be five times these figures (the diffraction efficiency of second-generation holograms is discussed below). If the safety requirements for using a helium-neon laser of 5 mw output in a display are satisfied, and a 2x power margin is allowed for overfill and optical losses, then the illumination will suffice for a hologram area of roughly .01m^2 (about 4" x 5"). Images of interest tend to be much larger than this, and unless the expense of an ion laser can be justified, display holography clearly must depend on thermal sources of illumination, despite their occasional safety hazards! The tradeoff between irradiance and coherence can be evaluated with reference to the requirements for near-perfect visual imaging. Proceeding from the granting equation, the blur in the direction of illumination for distant central image points is given by

$$\Theta^2 \text{ blur} = (\Delta \Theta \cos \Theta_i)^2 + (\frac{\Delta\lambda}{\lambda_i} \sin \Theta_i)^2 \tag{3}$$

where Θ_i is the image-to-illumination angle, $\Delta \Theta$ is the angular width of the (square) source, and $\Delta\lambda$ is the width of its output spectrum (centered on λ_i). The perpendicular blur is given by the first term alone. If we stipulate that an acceptable blur angle is 2 minutes, and Θ_i is 45°, then

$$\Delta \Theta \leq 2.0 \text{ min} \tag{4}$$

$$\Delta \lambda \leq 0.32 \text{ nm @ } 550 \text{ nm} \tag{5}$$

The highest available spectral radiances are provided by the very-high-pressure mercury short-arc lamps. These radiate energy into green (546 nm) and yellow (577/579 nm) spectral lines that are collision broadened to several nanometers width (c.a. 5 and 7 nm resp.), and surrounded by a continuum spectrum. Table 1 cites some data for commercially available lamps at 546 nm, including a 50% loss for a line-isolating interference filter. L_s is the source-to-hologram distance at 45° required to give 55 mw/m^2 at the hologram, and $\Delta \Theta \times \Delta \Theta$ is the angular height and width of the source at that distance.

If L_s is not a convenient distance, the arc can be used further away with a condenser to magnify its image. Unfortunately, the spectrum width is far too great, and filtering down to 0.3 nm is not feasible. A simple dispersion-compensation scheme would sharpen at least the central image,[27,28] if the 22-minute image blur were unacceptable.

If the depth of the images is limited with respect to the observer distance, d, so that no point is further behind the hologram than d/N-1, or further in front than d/N+1, then the spectrum width and source sizes can be increased by a factor of N without increased image blur. Because of the arc spectrum width without compensation, the depth of field should be reduced corresponding to $N \approx 10$, which would allow magnification of the arc, and hence higher hologram irradiance. The image luminance would increase by less than N^2 because the full magnification cannot be used with a large plate, and depth-of-field holograms, such as the "second generation" type. Their widely varying diffraction efficiency is limited to, say, 20% maximum for bright areas near the hologram plane, such as specular highlights, and is much less than 20% on the average.[29]

For filtered continuum sources of irradiance, the increase can go as N^3, and very satisfactory shallow reconstructions are possible with incandescent lamp/interference filter combinations, or in sunlight using the wavelength selectivity of reflection holograms. The latter will reconstruct an image over a spectrum width determined by the effective number of reflection layers, m.

$$\Delta\lambda \approx \lambda_i/m + 1 \qquad (6)$$

For a 6 μm thick emulsion, $m \approx 34$, $\Delta\lambda \approx 20$ nm. (Many reflection holograms are not completely bleached, so that only a few front layers are effective.) The size of the sun ($\Delta\lambda \approx 30$ min) and spectrum width are equally limiting at $\Theta_i \approx 15°$, giving $N \approx 18$ as a depth-of-field limitation. Such shallow images are well within the capabilities of carefully made integral photographs however, which produce natural color images in normal diffuse light.[30,31]

A word of caution: brighter is not always better! Beyond the point where the background light noise becomes comparable to the noise of the visual system, higher luminance images become progressively degraded.[32]

"Can You Make it Bigger?"

Although a single lamp can, in principle, illuminate a wide ring of holograms, operation with condensers quickly becomes limited by the power their finite aperture can gather. If a condenser of f-number FN is used to magnify an arc by M (virtual image) to allow illumination from a distance ML_s, the diameter of the illumination beam becomes

$$W = \frac{L_s}{FN} \cdot \frac{M}{M-1} \qquad (7)$$

which limits the hologram size. Similarly, illumination from distance L_s is limited to magnifications that allow the hologram to be filled.

There are also problems of making very large holograms that go beyond the handling and processing of bulky plates or large films. There is usually a maximum useful duration for any continuous-wave exposure, dictated by vibration and creep, and a more obvious energy limit for pulsed lasers, so that the size of the hologram is ultimately limited by the energy density required for exposure. The depth of field often scales with the hologram size, and is eventually limited by the finite coherence length of the source (unless it is "simulated" by optical means).[33] Nevertheless, quite large (2' x 3' routinely, 3' x 4' experimentally) pulsed-laser holograms of room-sized (12' x 12' x 9') scenes have been produced. Larger images might be projected via optical elements, or built up from composite holograms.

"Can You Do It in Color?"

Every holographer seems to have a pet scheme for producing images in natural color,[19,34] yet color holography remains in the laboratory. The problems are widely recognized: the need to avoid reconstruction of color separation images by incorrect wavelength illumination, and the

decrease of diffraction efficiency as the square of the number of independent images recorded on the same area. Reflection holography seems the most promising approach, but suffers from emulsion shrinkage effects in silver-halide materials as ordinarily processed. Also, there are no red-light short-arc lamps available, and the spectral radiance of continuum sources is so low ($L_e \lambda \approx$ 1.5 mW/mm^2 sr nm @ 550 nm for a 150 W xenon arc) as to limit the prospects for deep bright images. Nevertheless, commercial multicolor holography will probably be the next display advance.

"Can You Do an Outdoor Scene?"

Pulsed lasers have dramatically extended the scope of holography to include transient and fragile constructions, and small groups of people, but capturing a sunlit landscape is beyond even the contemplated state-of-the-art. However, an interesting line of developments does hold promise of "quasi-holographic" outdoor imaging.

Every eye-pupil sized area of a first generation hologram can be considered as a recording of a perspective view of the subject from that particular viewpoint, presented in exact registry with the views from a continuum of other areas. If instead, conventional photography is used to record perspectives from many discrete viewpoints, then they too can be merged into a single hologram for autosteroscopic presentation in exact registry. No such synthesized hologram, usually called a "holographic stereogram", can mimic all of the properties of a true hologram, but good quality visual imaging is possible over a depth comparable to the static depth of focus of the eye.[35]

Perspectives have been merged by frequency multiplexing for holograms located primarily in the image space,[36] and by spatial multiplexing (composite holograms) for holograms located near the viewer,[37] though these location distinctions have become increasingly arbitrary. The economies of eliminating vertical parallax were soon realized,[38] and a particularly flexible spatial multiplexing scheme emerged.[39] Here a camera records a sequence of perspectives in ordinary light as it is moved sideways, with the aperture diameter and perspective spacing carefully chosen.[40] Positives of these perspectives are rear-projected onto a diffusing screen with laser light, and narrow vertical strips of a plate some distance in front of the screen are exposed as holograms by introducing a coherent reference beam. The exposure location is changed for each perspective by moving a mask along the horizontal plate axis so that, after processing, an eye behind any strip sees only the perspective intended for it. If the geometry is suitably chosen, no abrupt changes of perspective will be noticed as the viewer moves from side to side, so that smooth parallax is presented, and a pleasing view of a horizontal-parallax-only image is available from well behind the hologram. The hologram can also be back-projected to present a synthesized real image for exposure of

a second-generation-frequency-multiplexed hologram.[41] If the perspectives are suitably made, the vertical strip mask can be stationary, and the plate or film moved behind it, which permits the generation of 360° cylindrical holographic stereograms, and the use of a cylindrical lens to conserve projection light.[40] Several Japanese image research laboratories have been active in holographic stereograms.

Holographic stereograms have been of particular interest for three-dimensional viewing of computer-generated,[41] electron microscope,[42] and x-ray images.[43] A variation is holographic tomosynthesis, in which a hologram is spatially multiplexed to project images from points corresponding to the many x-ray source locations, often along a circular track. Instead of viewing the composite real image stereoscopically, a ground glass is introduced to select a single plane of focus, which is equivalent to an x-ray tomographic "slice."[44] As an optical back-projection scheme, it is an implementation of the "smearing algorithm" for the wider problem of reconstruction of a N-dimensional signal from its (N-1) dimensional projections.[45]

"Can You Make it Move?"

Television and motion pictures were early targets for holographic speculation, and remain so today.[46,47] The information rate is so enormous as to require prohibitive bandwidths or film flows, unless drastic reduction or compression is achieved.[14,16] One of the first strategies is, of course, to eliminate vertical parallax, [15,48] but to the author's knowledge, the only publicly demonstrated display-sized holographic movie is the direct-view scheme of DeBitetto.[49] Future medium-screen sized "movies", particularly in color, are likely to be of the horizontal-parallax-only projected image type.

In the meantime, repetitive motion is available from the number of images that can be merged into a single emulsion by spatial or frequency multiplexing (several horizontal-parallax-only images vertically arrayed), or a few Bragg-angle selected full-parallax views, sequenced by tipping the plate.[50]

An interesting scheme for incorporating longer-term repetitive motion into cylindrical holographic stereograms has been developed by Lloyd Cross,[51] a leading proponent of holographic stereograms in the United States. He sequentially records over a thousand perspectives of a subject on a slowly turning pedestal, while the subject dances, plays an instrument, grimaces, etc. The perspectives are combined via projection and masked exposure, such as previous' · described, to produce a cylinder of vertical strip holograms, which is slowly rotated in front of the viewers. Although the images seen by the right and left eyes differ by the subject motion between their recordings as well as by parallax due to the different angles of view, Cross has shown that the disparities due to subject motion need not disrupt the gestalt of a completely stereoscopic image, if the stereogram turns continuously. The result is a

convincing impression of a three-dimensional figure moving and turning within the cylinder. Recent developments allow the use of a white-light illumination source, and extension of the repeat time beyond 45 seconds. Such stereograms, known variously as "multiplex holograms" and "integrafs," will undoubtedly be widely displayed.

"Can You Make the Image Clearer?"

This includes the many remaining questions of image quality, most of which occur only to fellow holographers. An important exception is the topic of "speckles," which remain "Enemy Number One" of holography.[52] So far, all attempts at speckle reduction have taken either decrease of image luminance, contrast, resolution, or depth of field as a price (Ref. 53 includes a bibliography on speckle reduction). The most familiar technique is wavelength-averaging in reflection holograms and image-plane transmission holograms, where the speckle first becomes localized in the hologram plane and then loses contrast as the effective reconstruction bandwidth is increased. The price is a limited depth of field, and no widely useful speckle reduction technique for deep images has been developed, though research in speckle and its applications is continuing at a vigorous pace.

Several other types of noise degrade holographic image quality. Silver-halide materials exhibit two "granularity noises," one due to scattering of the reconstruction irradiation by the granular image microstructure,[54] and the other a reconstruction of the scatter of the exposing irradiation.[55] We find that processes that increase diffractiom efficiency also increase granularity noise.[21,56] Granularity in the finest-grained emulsions is usually overwhelmed by intermodulation noise, discussed earlier, which arises to some extent in all phase hologram materials.[57] Often "cosmetic" noises are equally noticeable. Such artifacts as fringes, shrinkage effects, drying marks and clean laminations are in the domain of the holographer's black arts. Others, due to flaws in material manufacture, vary widely with type and source, and some respond to special treatment.[26]

"Can You Get Rid of that Light?"

In a word, no. Holographic image formation depends on illumination having specific geometrical and coherence properties. The light source, whether a laser, mercury arc, incandescent lamp, or the sun, will have to be positioned where the designer intended, and there cannot be a comparable source in its vicinity. For published and sun-powered holograms, this means some effort for rough alignment and waiting for a sunny day. But in most displays that are self-contained or under the designer's control, illumination sources can and eventually must be made unnoticeable. They may imply certain space or location requirements, but a casual observer need never suspect that a peculiarly bright small light is nearby!

"Can You Make It Cheaper?"

Holography remains a redious and painstaking craft, requiring considerable technical competence and specialized equipment for reliable first-rate results. These costs, compounded by the overhead demanded by corporate structures and marketing intermediaries, have priced custom holographic displays at the top of the prestige market, which has shrunk dramatically in recent years. In search of a wider market, the new generation of holographic ventures are low-overhead operations, depending on increasingly available surplus equipment, large-scale production, and semi-automatic operations (such as the step-and-repeat generation of holographic stereograms) to keep unit costs down.

The material cost of a display is generally dominated by the hardware, illuminator, etc., but for mass-produced holograms is ultimately limited by the costs of coated photosensitive materials. A possibility for very cheap holograms lies in the embossing of plastic films to produce thin phase transmission/reflection holograms.[58] Despite their shortcomings relative to thick holograms, they can produce horizontal-parallax-only images with sunlight illumination.

Naturally, questions about cost often arise much earlier on, and because individual advances do not involve conflicts with basic physics (except perhaps for speckle) their progress is mainly a question of acceptable cost. Improvements in photosensitive materials, such as a wider index range and steeper exposure response, and particularly in high spectral radiance light sources would considerably loosen the constraints on display designs. However, added process steps or optical display elements might finally overburden a workable system. Non-optical considerations, such as portability, maintainability, life time and safety must also bear on the engineering of practical designs.

WHITHER HOLOGRAPHY?

Thus far in the history of holographic displays, the medium has been most of the message. More supporting text has been devoted to lasers and holography than to any purpose of the display, and many of the effects could have been created with incoherent optics or plastic models. Although that process of public education should continue for some time, holography must eventually become an astonishingly effective, but anonymous medium. Based on the considerable achievements to date, display holography is developing along two separate but ultimately interdependent lines.

In order to meet an educated viewer's rising expectations, holographic image quality must approach high photographic standards. Images must be bright, clear, deep, of any scene imaginable, in black and white or natural color, and perhaps moving. We have argued that these goals are not in conflict with basic laws of physics, so that their attainment is ultimately a question of cost. Granted that some of them may require a skirting of the rules by departing from pure classical holography via reduced parallax, photographic/holographic hybrids, and other means, but in the end the undeniable appeal of a high-quality autostereoscopic image will justify them all. Holographers have proven very adept at inventing around formidable obstacles, but the best use of their accomplishments requires other insights as well.

In 1908, Lippmann hoped that integral photography would at last open a "window upon reality,"[59] but it is only with the emergence of holography that the esthetics of such a window view are seriously being considered. Similar questions arise in other media, of course, but the experience, and hence the answers, are distinct. Although esthetic exploration will play an important role in development of holography, artists are finding that, as the directions of research have changed, most of the laboratory facilities have been dismantled and opportunities for fine-arts projects have practically vanished. Only a few artists, such as Benyon[60] and Casdin-Silver[61] (with whom the author has collaborated on several holograms) have been able to work at all consistently with holograms as art objects.

The establishment of a Holographic Arts Program at the Cooper Hewitt Museum/Smithsonian Institution[62] is therefore particularly significant. In its functions of maintaining much of the nation's technical capability in display holography, and making it available to artists and experimenters, it will serve as a catalyst for esthetic and technical advances, which will in turn stimulate each other.

At the same time, holography is enjoying a steadily increasing role in undergraduate physics teaching, and in photography and fine-arts curricula. Specialized schools and courses are preparing artists/artisians to work with the new technology. Three or four vigorous young companies are now producing images, and report a gradual upswing of customer interest. All of these are contributing to the technical, esthetic, and educational foundations that the next wave of holographic enthusiasm will build upon and be sustained by.

ACKNOWLEDGMENTS

The author has had the benefit of many hours of discussion on this topic with friends and colleagues too numerous to mention individually here. For information relating directly to this article, he is grateful to H. Casdin-Silver, K. Baxter, T. Jeong, J. Burns, J. Goldberg, R. Schinella, and P. Nicholson.

Table 1. Mercury Arc Characteristics

Lamp*	Power	I_e [illegible] 546 nm	L_s	[illegible] x [illegible]
	W	mW/sr*+	m	min
III-110	100	75	.98	.79 x .79
III-500-2	500	375	2.2	5.2 x 3.0

*Courtesy of Illumination Industries, Inc.
+Includes 50% interference filter loss.

REFERENCES

1. E. N. Leith and J. Upatnieks, "Wavefront Reconstruction with Diffused Illumination and Three-Dimensional Objects," J. Opt. Soc. Amer. 54, 1295-1301 (1964).
2. L. Lessing, "Getting the Whole Picture from Holography," Fortune Magazine, Sept. 1971, p. 110 et seq.
3. R. Schinella, "Holography: The Ultimate Visual," Optical Spectra 7, 27-34 (July 1973).
4. J. F. Asmus, G. Guattari, L. Lazzarini, G. Musumeci, and R. F. Wuerker, "Holography and the Conservation of Statuary," Studies in Conservation 18, 49-63 (1973).
5. J. Upatnieks, "360 Degrees Hologram Displays for Educational Uses," J. Opt. Soc. Amer. 64, 1396A (1974).
6. D. Davis "The Nth Dimension," Newsweek Magazine, 15 June 1970, p. 110.
7. R. N. Winner and J. H. Brindle, "A Holographic Visor Helmet-Mounted Display System," Conference Record of the 1974 Conference on Display Devices and Systems (Society of Information Display, Oct. 9-10 1974 issue) pp. 43-52.
8. B. R. Clay and D. A. Gore, "Holographic Moving Map Display," Optical Eng'g. 13, 435-439 (1974).
9. D. Gabor, "Three Dimensional Picture Projection," U. S. Patent 3,479,11 (issued 18 Nov. 1969).
10. T. H. Jeong, "Cylindrical Holography and Some Applications," J. Opt. Soc. Amer. 57, 1396-1398 (1967).

11. F. B. Rotz and A. A. Friesem, "Holograms with Non-Pseudoscopic Real Images," Appl. Phys. Lett. 8, 146-148 (1966).
12. L. Rosen, "Holograms of the Aerial Image of a Lens," Proc., IEEE 55, 79-80 (1967).
13. V. S. Srinivasan, "Beam Reduction in Holography for Holographic Movies," Applied Optics 9, 2187-2189 (1970).
14. K. A. Haines and D. B. Brumm, "Holographic Data Reduction," Applied Optics 7, 1185-1189 (1968).
15. D. J. DeBitetto, "Bandwidth Reduction of Hologram Transmission Systems by Elimination of Vertical Parallax," Appl. Phys. Lett. 12, 176-178 (1968).
16. L. H. Lin, "A Method of Hologram Reduction by Spatial Frequency Sampling," Applied Optics 7, 545-548 (1968).
17. S. A. Benton, "Hologram Reconstructions with Extended Incoherent Light Sources," J. Opt. Soc. Amer. 59, 1545A (1969).
18. R. J. Collier, C. B. Burckhardt and L. H. Lin, Optical Holography, (Academic Press, N.Y., 1971) Chs 8 & 9.
19. W. T. Cathey, Optical Information Processing and Holography (John Wiley & Sons, N.Y., 1974) Ch. 9.
20. J. C. Urbach, "Advances in Hologram Recording Materials," Proc. SPIE Seminar-in-Depth: Developments in Holography (Vol. 25, April 1971) pp. 17-42.
21. A. Graube, "Advances in Bleaching Methods for Photographically Recorded Holograms," Applied Optics 13, 2942-2946 (1974).
22. T. A. Shankoff, "Phase Holograms in Dichromated Gelatin," Applied Optics 7, 2101-2105 (1968).
23. B. L. Booth, "Photopolymer Material for Holography," Applied Optics 14, 593-601 (1975).
24. R. A. Bartolini, "Characteristics of Relief Phase Holograms Recorded in Photoresists," Applied Optics 13, 129-139 (1974).
25. J. Upatnieks and C. Leonard, "Efficiency and Image Contrast of Dielectric Holograms," J. Opt. Soc. Amer. 60, 2970305 (1970).
26. K. S. Pennington and J. S. Harper, "Techniques for Producing Low-Noise Imporved Efficiency Holograms," Applied Optics 9, 1643-1650 (1970).
27. D. J. DeBittetto, "White-Light Viewing of Surface Holograms by Simple Dispersion Compensation," Appl. Phys, Lett. 9, 417-418 (1966).
28. R. H. Katyl, "Compensating Optical Systems: Pt. 1, Broadband Holographic Reconstruction," Applied Optics 11, 1241-1247 (1972).
29. G. B. Brandt, "Image Plane Holography," Applied Optics 8, 1421-1429 (1969).
30. C. B. Burckhardt, "Optimum Parameters and Resolution Limitations of Integral Photograph," J. Opt. Soc. Amer. 58, 71-76 (1968).
31. R. L. DeMontebello, "Integral Photography," U. S. Patent 3,503,315 (issued 31 March 1970).

32. A. Rose, Vision: Human and Electronic (Plenum Press, N.Y. 1975) Ch. 5.
33. D. Gabor, "Panoramic Holograms," U. S. Patent 3,545,836 (issued 8 Dec 1970).
34. Ref. 18, Ch. 17.
35. J. T. McCrickerd, "A Comparison of Stereograms: Pinhole, Fly's Eye and Holographic," J. Opt. Soc. Amer. 62, 64-70 (1972).
36. R. V. Pole, "3-D Imagery and Holograms of Objects Illuminated in White Light," Appl. Phys. Lett. 10, 20-21 (1967).
37. J. T. McCrickerd and N. George, "Holographic Stereograms from Sequential Component Photographs," Appl. Phys. Lett. 12, 10-12 (1968).
38. J. D. Redman, "The Thre-Dimensional Reconstruction of People and Outdoor Scenes using Holographic Multiplexing," Proc. SPIE Seminar-in-Depth Holography (Vol. 15, 1968) pp. 117-122.
39. D. J. DeBitetto, "Holographic Panoramic Stereograms Synthesized from White Light Recordings," Applied Optics 8, 1740-1741 (1969).
40. T. Kashara, Y. Kimura and M. Kawai, "3-D Construction of Imaginary Objects by the Method of Holographic Stereogram" in Applications of Holography, E. V. Barrekette et. al. eds. (Plenum Press, N.Y., 1969) pp. 19-34.
41. M. C. King, A. M. Noll and D. H. Berry, "A New Approach to Computer Generated Holograms," Applied Optics 9, 471-475 (1970).
42. J. A. Chapman, S. M. W. Grundy, W. P. Wolton and J. D. Redman, "Three-Dimensional Reconstructions from Electron Micrographs by Holography," Proc. 5th European Congress on Electron Microscopy (1972) pp. 606-607.
43. J. D. Redman, W. P. Wolton and E. Shuttleworth, "Use of Holography to make Truly Three-Dimensional X-ray Images," Nature 220, 58-60 (1968).
44. M. Kock and U. Tiemens, "Tomosynthesis: A Holographic Method for Variable Depth Display," Optics Comm. 7, 260-265 (1973).
45. R. M. Merserau and A. V. Oppenheim, "Digital Reconstruction of Multidimensional Signals from Their Projections, Proc. IEEE 62, 1319-1338 (1974).
46. E. N. Leith, D. B. Brumm and S. S. H. Hsiao, "Holographic Cinematography," Applied Optics 11, 2016-2023 (1972).
47. D. Casasent and R. L. Herold, "Television Based Fourier Holographic System," Applied Optics 13, 2268-2273 (1974).
48. D. S. St. John, "Three Dimensional Large Screen Movie Techniques Employing Holography and a Cylindrical Optical System," U. S. Patent 3,625,584 (issued 7 Dec. 1971).
49. D. J. DeBitetto, "A Front-Lighted 3-D Holographic Movie," Applied Optics 9, 498-499 (1970).
50. E. N. Leith, A Kozma, J. Upatnieks, J. Marks, and N. Massey, "Holographic Storage in Three-Dimensional Media," Applied Optics 5, 1303-1311 (1966).

51. The School of Holography, 454 Shotwell Street, San Francisco, Calif. 94110.
52. D. Gabor, "Laser Speckle and Its Elimination," IBM J. Res. Develop. 14, 509-514 (1970).
53. N. George and A. Jain, "Speckle Reduction Using Multiple Tones of Illumination," Applied Optics 12, 1203-1212 (1973).
54. J. W. Goodman, "Film-Grain Noise in Wavefront Reconstruction Imaging," J. Opt. Soc. Amer. 57, 493-502 (1967).
55. K. Biedermann, "The Scattered Flux Spectrum of Photographic Materials for Holography," Optik 31, 1-23 (1970).
56. S. A. Benton, "Intra-Emulsion Diffusion-Transfer Processing of Volume Dielectric Holograms," J. Opt. Soc. Amer. 64, 1393A (1974).
57. R. G. Zech, Data Storage in Volume Holograms, (PhD. thesis, Univ. of Michigan, 1974) Ch. 2 (Univ. Microfilms order no. 74-25, 369).
58. R. Bartolini, W. Hannan, D. Karlsons and M. Lurie, "Embossed Hologram Motion Pictures for Television Playback," Applied Optics 9, 2283-2290 (1970).
59. G. Lippmann, "Integral Photography," Comptes Rendus 146, 446-451 (1908).
60. M. Benyon, "Holography as an Art Medium," Leonardo 6, 1-9 (1973).
61. Dept. of Physics, Brown Univ., Providence R.I.
62. National Museum of Design, 9 E. 90th Street, New York, NY 10028.

HIGH ACCELERATION COCKPIT

MR. P. KULWICKI & MR. J. SINNETT

HIGH ACCELERATION COCKPIT

3rd ADVANCED AIRCREW DISPLAY SYMPOSIUM

NAVAL AIR TEST CENTER

20 MAY 1976

Aerospace Medical Research Laboratory

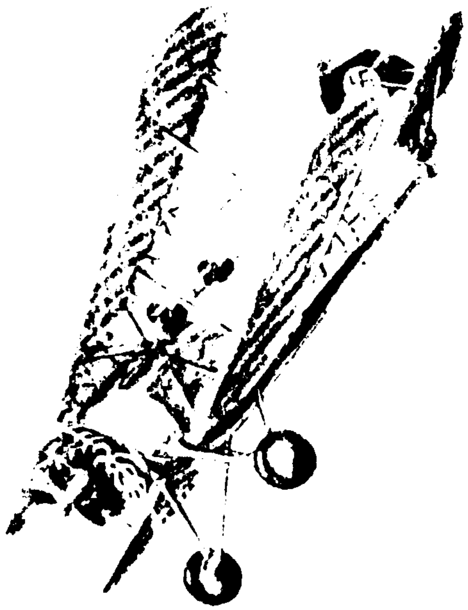
AIR FORCE FLIGHT DYNAMICS LABORATORY

MCDONNELL DOUGLAS

CORPORATION

GP76 0421 3
HG 564

EARLY FLIGHT DEMONSTRATION

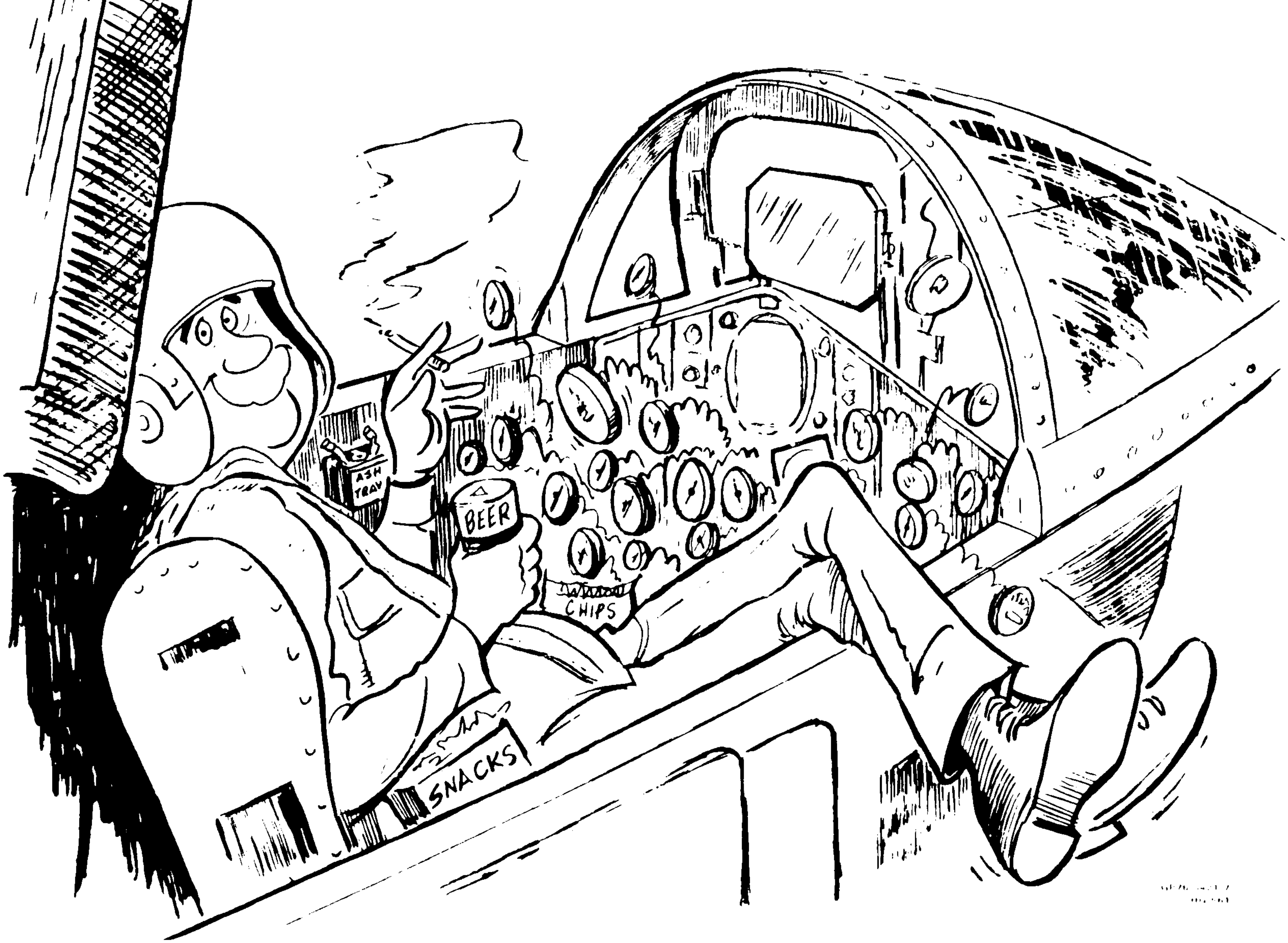


HEINKEL HE 50
1938
LUFTWAFFE

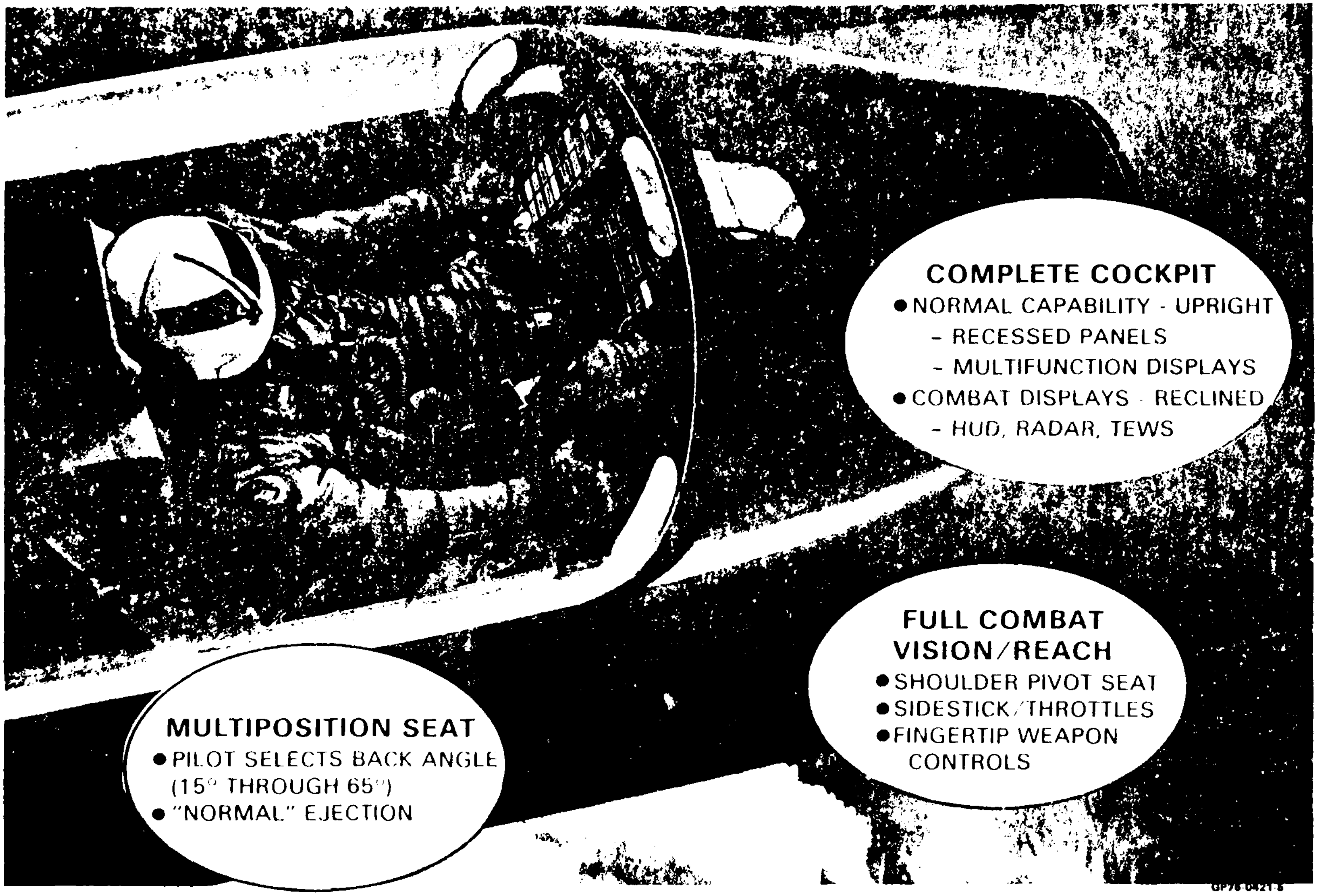
GRUMMAN F7F-2N
1954
USN-NADC

GP76 0421 2
HG 562

R&D BREAKTHROUGHS REDUCE PILOT WORKLOAD

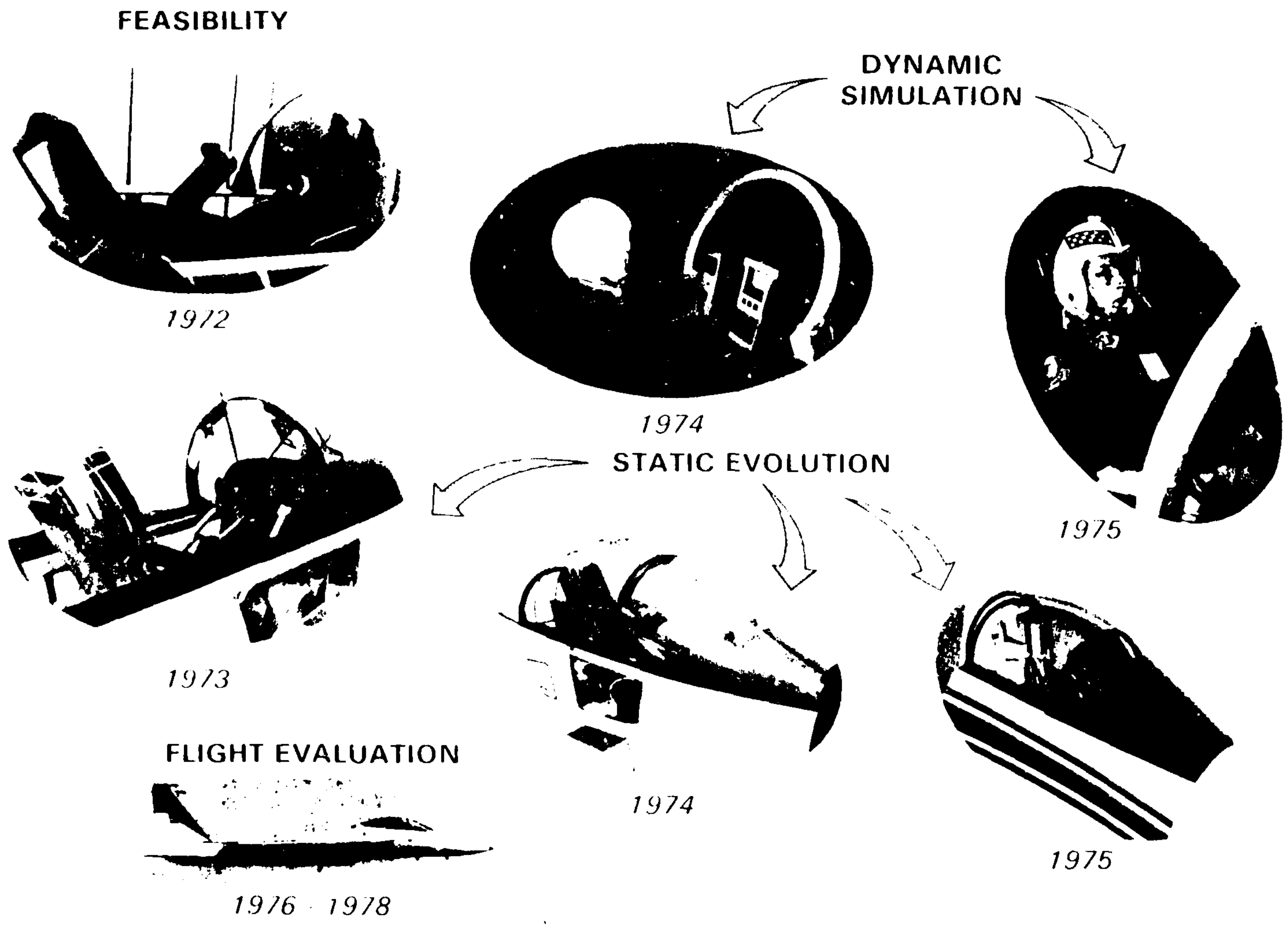


HAC PRACTICABLE WITH TODAY'S TECHNOLOGY



GP78-0421-5

R&D ROADMAP

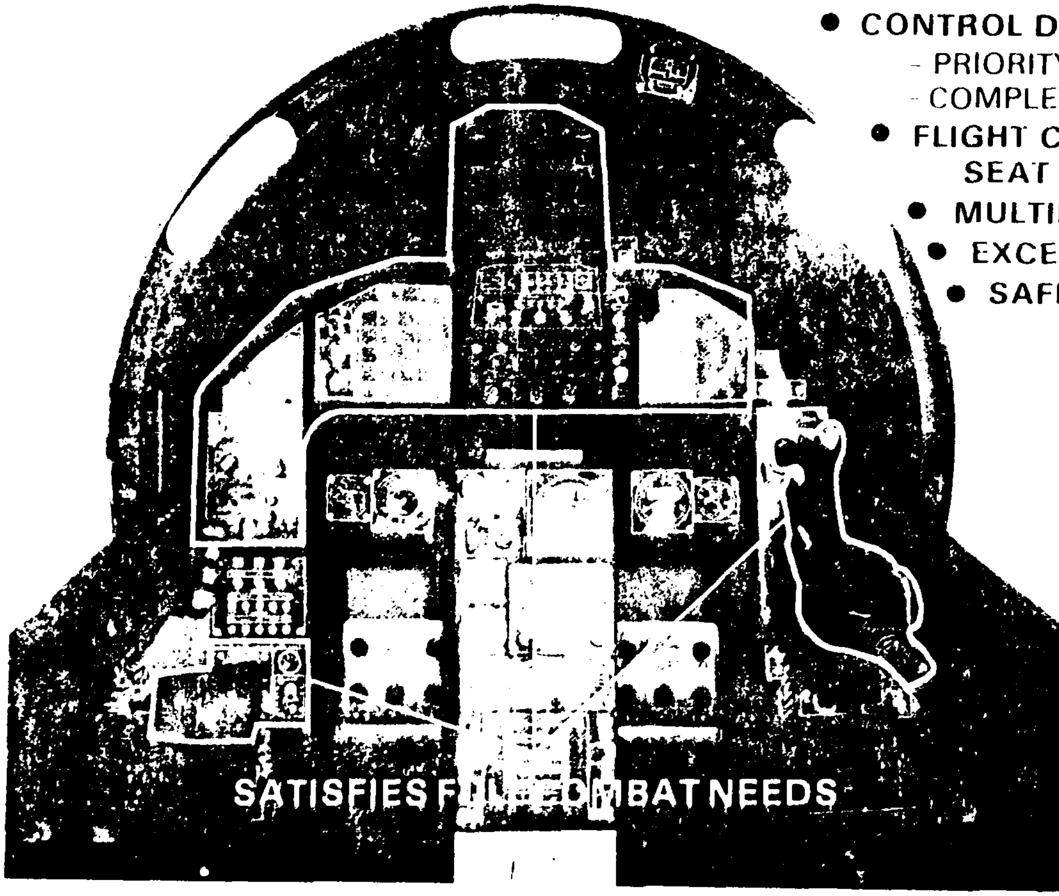


FEASIBILITY
1972
DYNAMIC SIMULATION
1974
1975
STATIC EVOLUTION
1973
1974
1975
FLIGHT EVALUATION
1976 - 1978

HAC

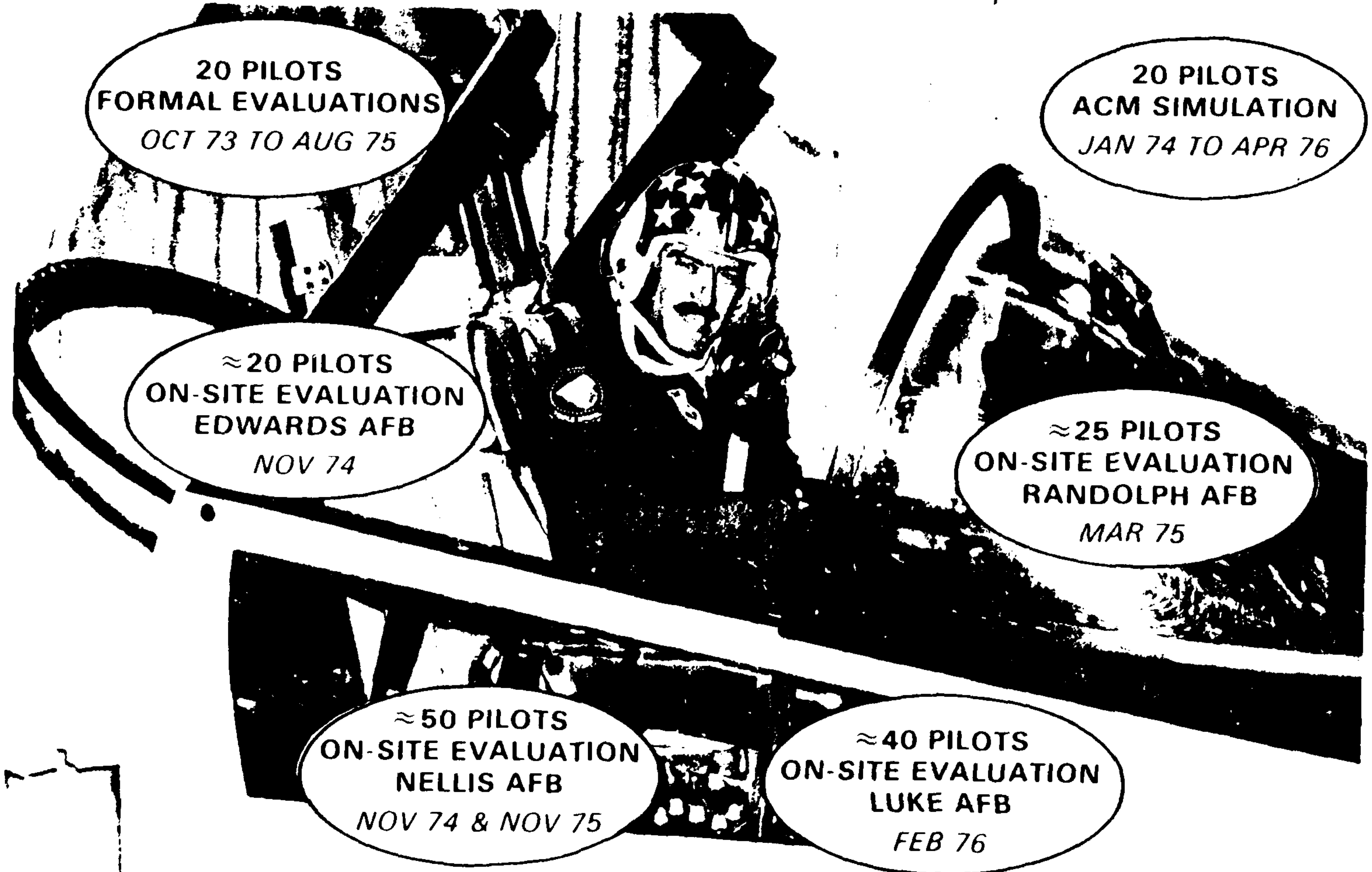
DESIGN APPROACH

- DETERMINE "MISSION NEEDS"
- PROVIDE NECESSARY CAPABILITY
- CONTROL DISPLAY
  - PRIORITY FOR COMBAT
  - COMPLETE COCKPIT, UPRIGHT
- FLIGHT CONTROL FROM ALL SEAT POSITIONS
- MULTIPOSITION SEAT
- EXCELLENT EXTERNAL VISION
- SAFE ESCAPE



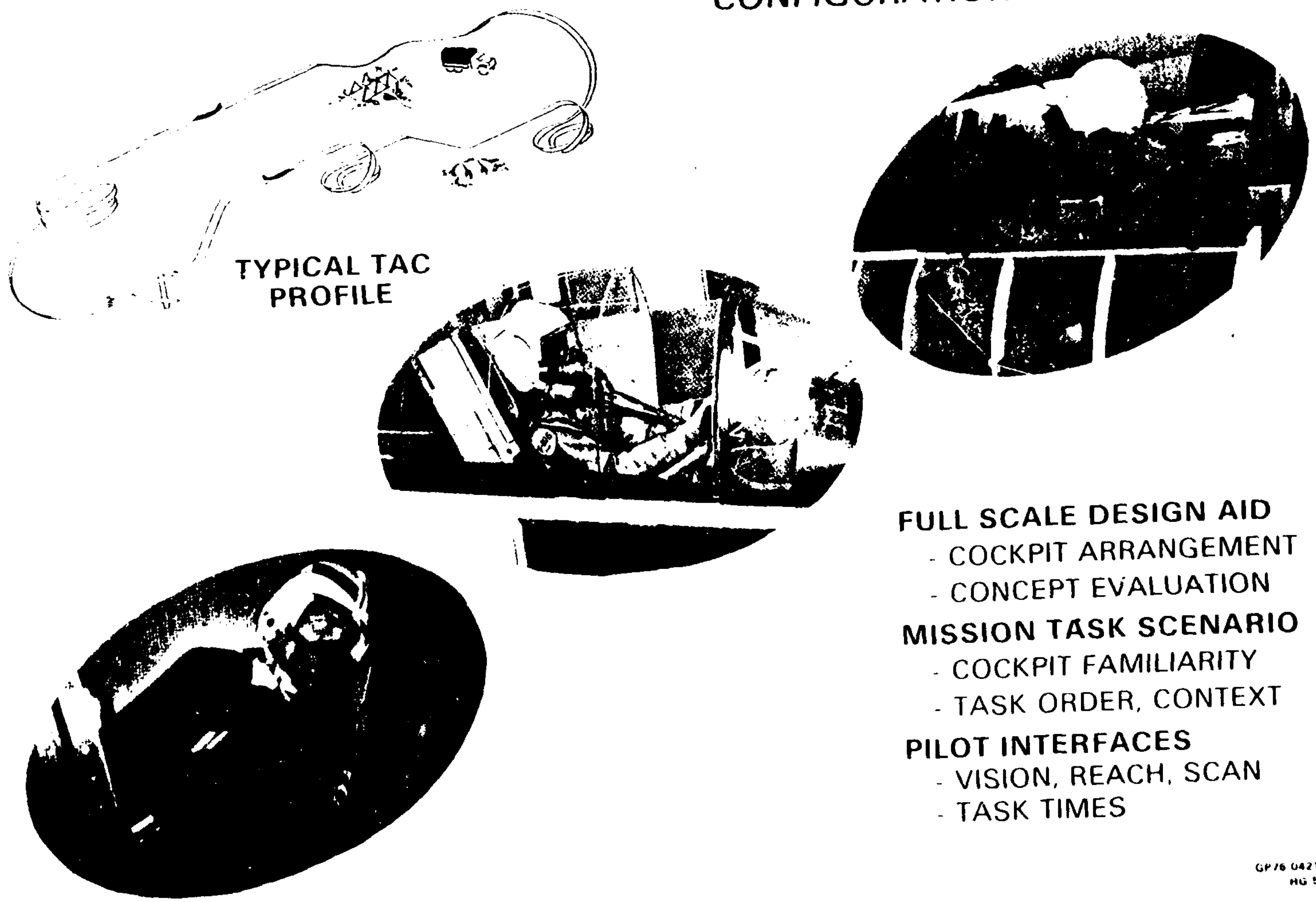
GP76 0421 12
HG 663

CONTINUAL OPERATOR INVOLVEMENT
(≈175 TAC PILOTS, > 250,000 FLT HR EXPERIENCE, 1st LT TO M/GEN)



STATIC SIMULATION

CONFIGURATION EVOLUTION



FULL SCALE DESIGN AID
- COCKPIT ARRANGEMENT
- CONCEPT EVALUATION

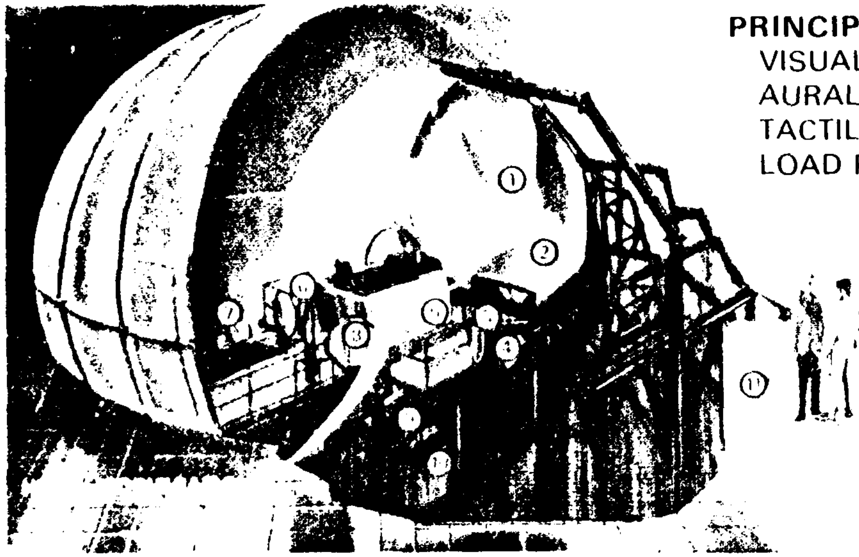
MISSION TASK SCENARIO
- COCKPIT FAMILIARITY
- TASK ORDER, CONTEXT

PILOT INTERFACES
- VISION, REACH, SCAN
- TASK TIMES

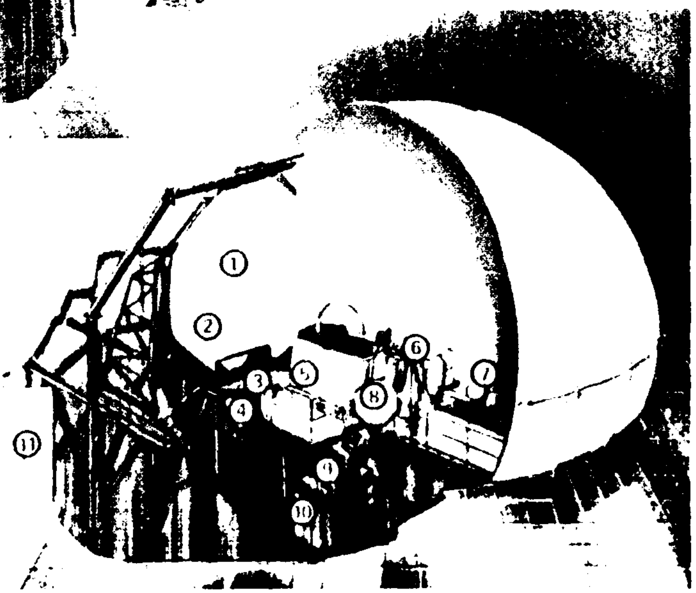
GP76 0421 6
HG 560

HAC

COMBAT SIMULATION



PRINCIPAL CUES:
- VISUAL: HORIZON, TARGET, WEAPONS
- AURAL: AERO, ENGINE, WEAPONS
- TACTILE: CONTROL FEEL, BUFFET
- LOAD FACTOR: G-SUIT, LIGHT LOSS



FREEPLAY: ONE vs ONE

BALANCED TESTS:
- START CONDITIONS
- PILOT PAIRINGS

TEST CONFIGURATION SIMILARITIES
- CREW STATION
- FIRE CONTROL/WEAPONS
- FLIGHT CONTROLS

COMMON OPPONENT

DYNAMIC SIMULATION FOR CONCEPT DEVELOPMENT

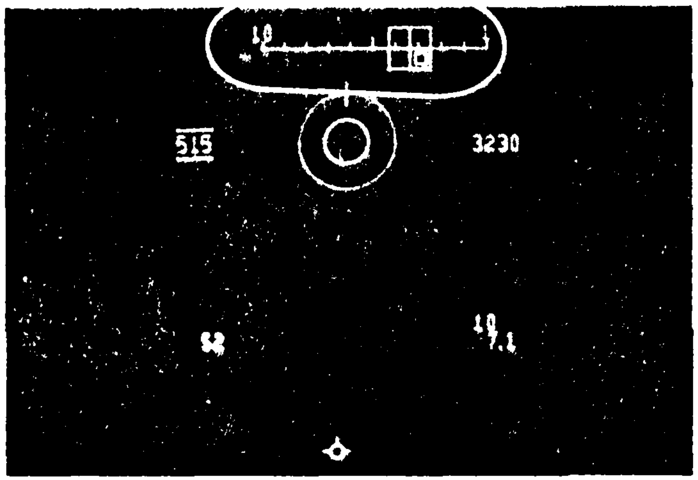
MAJOR PILOT INTERFACES
- SEAT POSITION MOTION
- SIDE STICK INTEGRATION
- PEDAL MOTION
- HUD FIELD OF VIEW
- PERSONAL EQUIPMENT

USABLE COMBAT CAPABILITY
- WEAPON SYSTEM INTEGRATION
- CONTROL/DISPLAY ADEQUACY
- FLIGHT CONTROLS
- EXTERNAL VISION
- COMBAT MEASURES

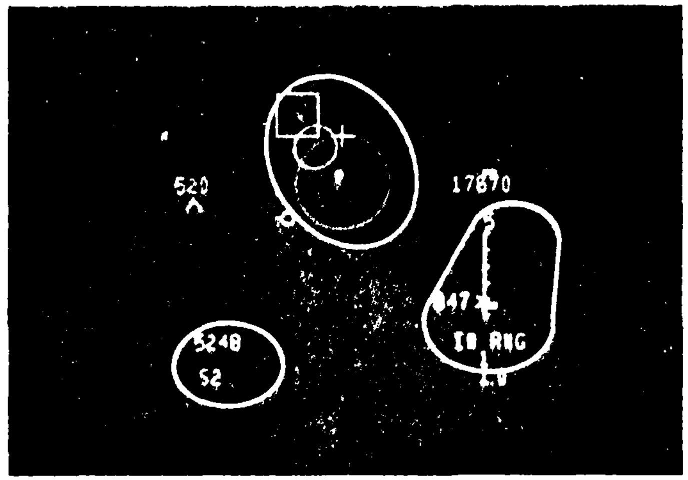
GP76 0421 9
HG 556

DISPLAY DEVELOPMENT IN OPERATIONAL CONTEXT

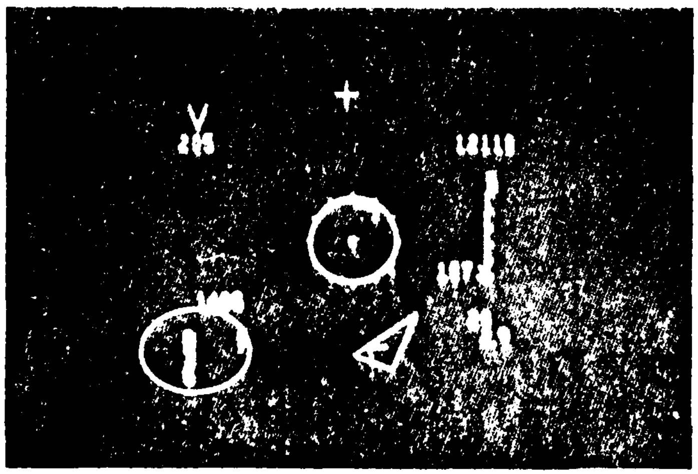
INTERACTIVE ACM, FULL SYSTEMS OPERATION



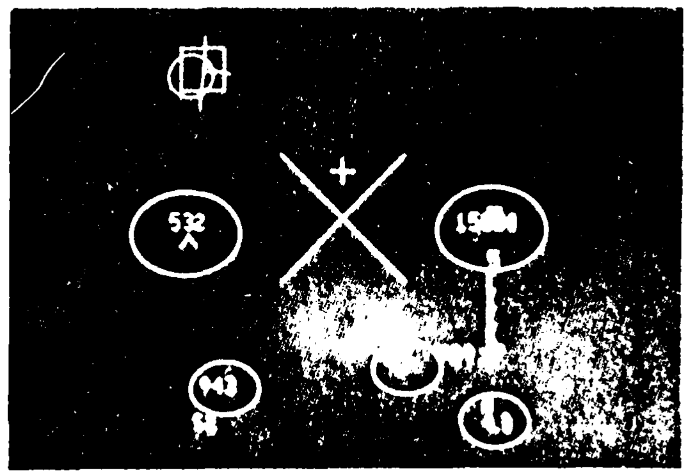
TACTICAL WARNING



FIRE CONTROL



ARMAMENT SELECT/STATUS



FLIGHT MANAGEMENT

REDUCED PILOT WORKLOAD TRANSFERS TO COMBAT PAYOFF

SYSTEM (A)

- FLY AIRPLANE, TRACK TARGET
- MANUAL SEEKER LOCK-ON
  - MONITOR SNR TONES
  - DEPRESS "UNCAGE"
- MONITOR IN-RANGE AND ANGLE PARAMETERS
- SHOOT WHEN IN "GOOD" SOLUTION

SYSTEM (B)

- FLY AIRPLANE, TRACK TARGET
- AUTO SEEKER LOCK-ON
  - TONE
  - SEEKER DISPLAY
- FLASH "ASE" FOR SHOOT
- SHOOT WHEN ASE FLASHES

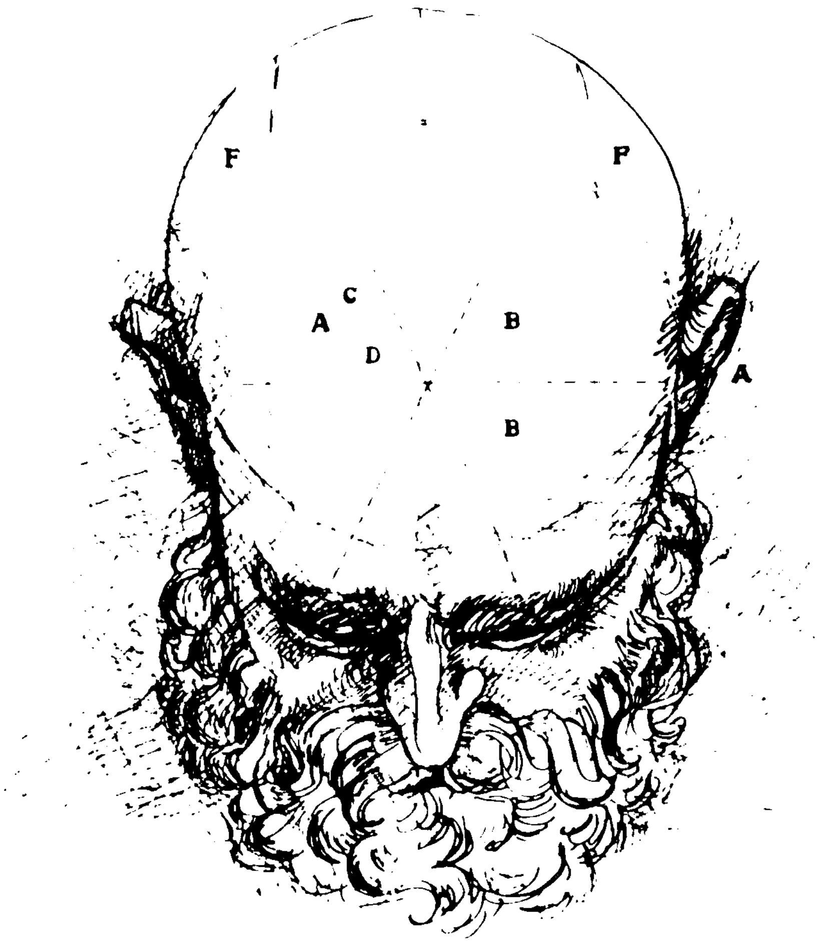
TIME IN SRM ENVELOPE

96 AIRCRAFT ENGAGEMENTS EACH:

(82 SHOTS/61 HITS)	(A)	1.15 SEC/ENGAGEMENT
(110 SHOTS/91 HITS)	(B)	2.78 SEC/ENGAGEMENT

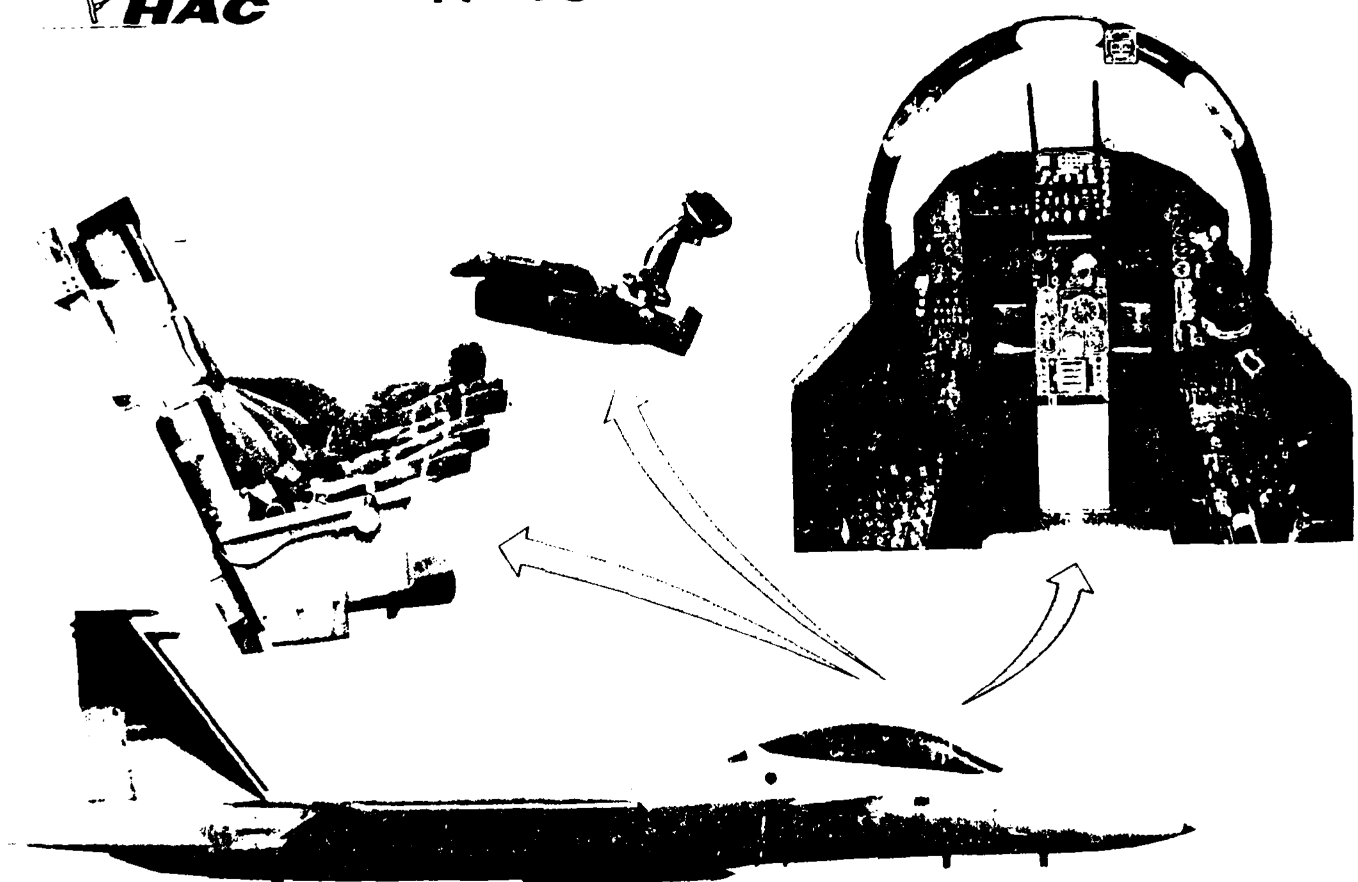
HG 491
GP75 0855 3

The Toughest Part Of Control Display Is The Last Few Inches

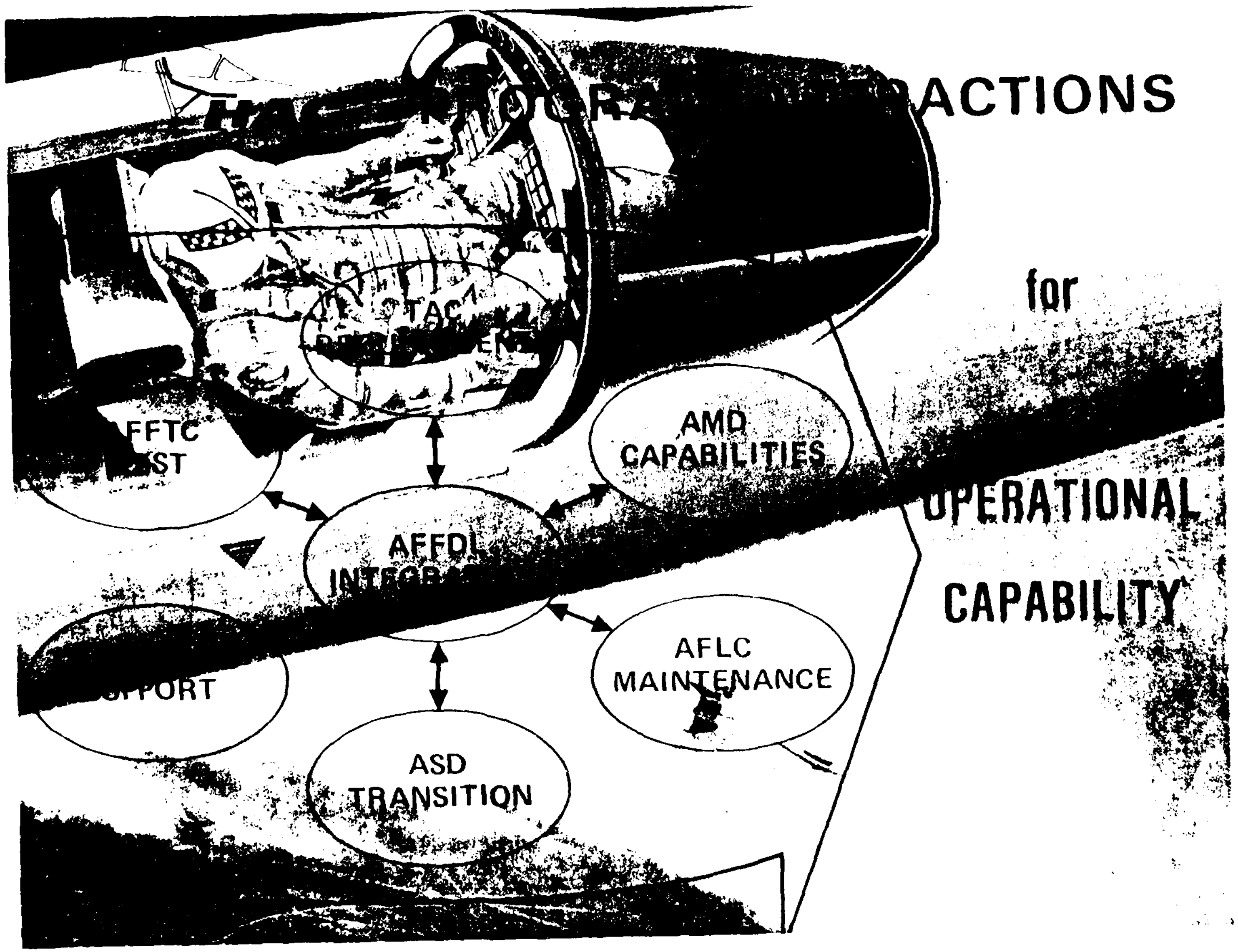


HAC

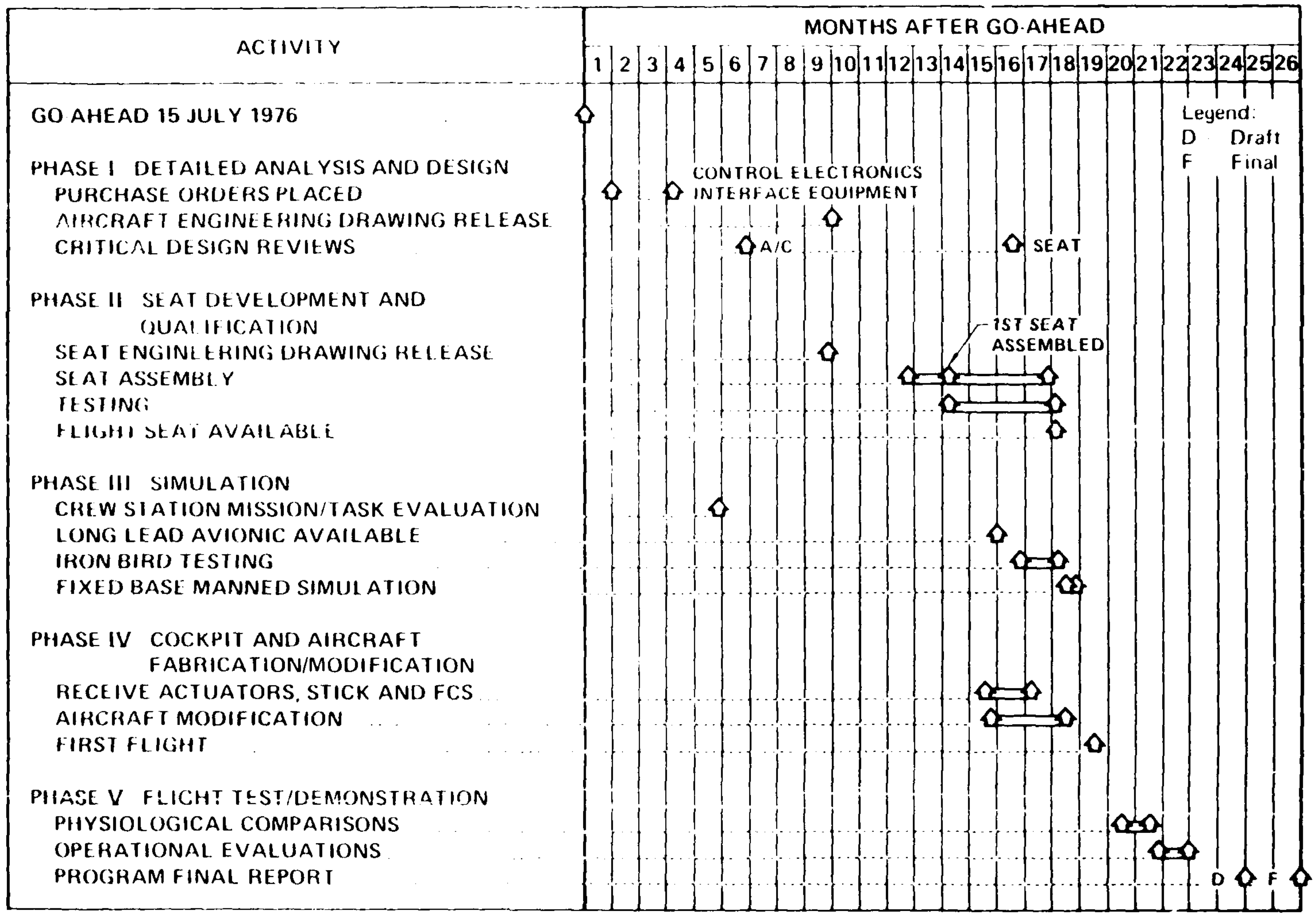
TF-15 DEMONSTRATOR



COMPONENT INTEGRATION TO PERMIT AN OPERATIONAL EVALUATION AND DETERMINE SYSTEM LIMITATIONS


ACTIONS
for
OPERATIONAL
CAPABILITY
AFFTC
AMD
CAPABILITIES
AFFDL
AFLC
MAINTENANCE
ASD
TRANSITION

PROGRAM SCHEDULE

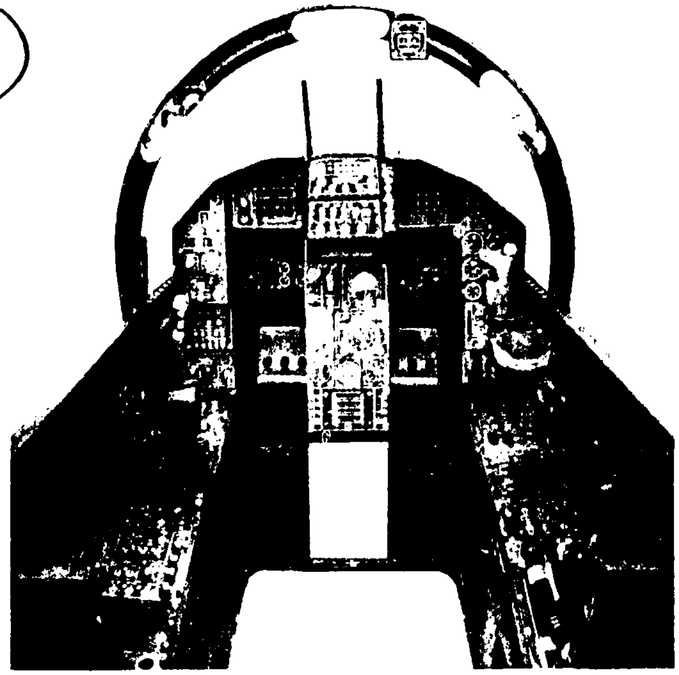


HAC

DEMONSTRATES MORE THAN A LAY-BACK SEAT

RECESSED DISPLAYS

FULL WEAPONS CONTROL/ CAPABILITY



SHORT THROW ELEVATED PEDALS

SIDE STICK CONTROLLER

HIGH PERFORMANCE EJECTION SEAT

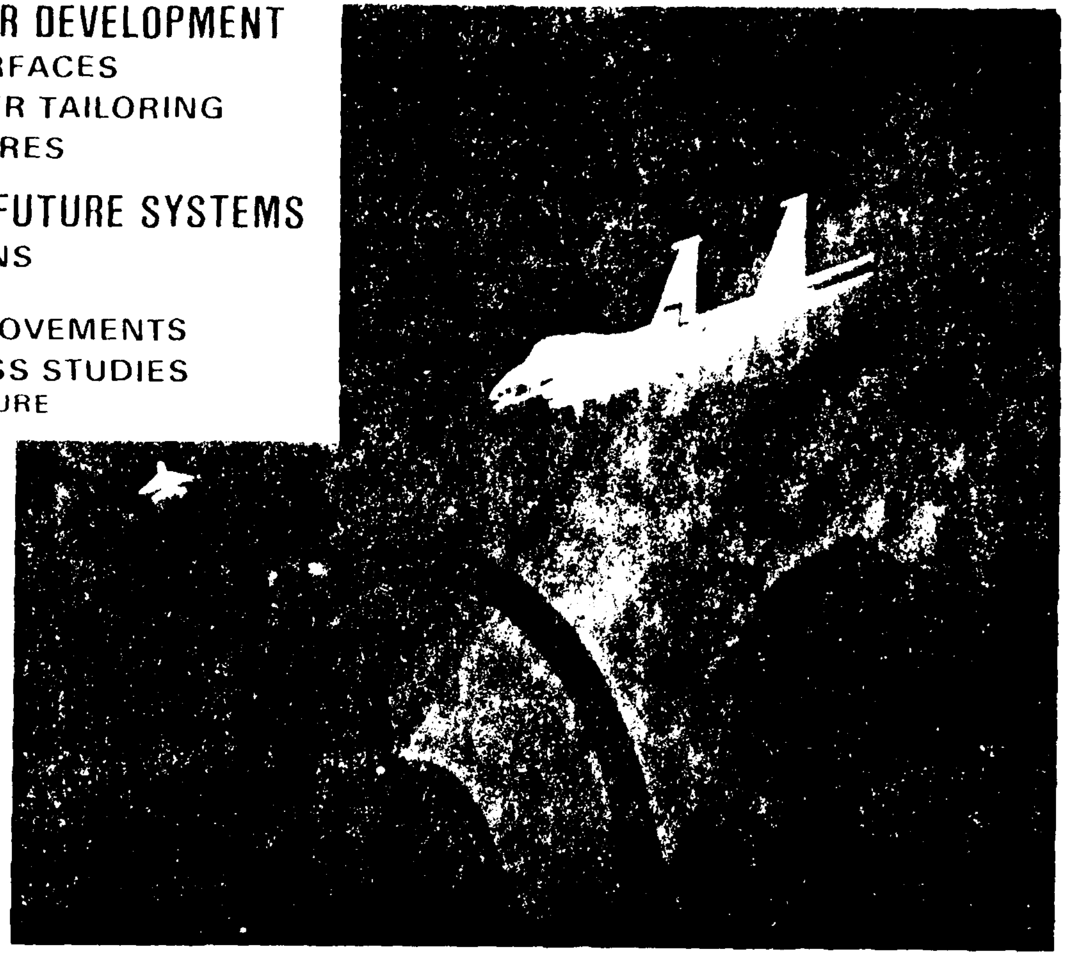
GP76 0392 3
HG 550

HAC

FLIGHT SIMULATION GOALS

HAC/TF-15 DEMONSTRATOR DEVELOPMENT
- MAJOR COCKPIT INTERFACES
- SIDESTICK CONTROLLER TAILORING
- FLIGHT TEST PROCEDURES

TACTICAL IMPLICATIONS/FUTURE SYSTEMS
- AIR-TO-AIR/SRM + GUNS
  1 vs MULTIPLE
- AIR-TO-SURFACE IMPROVEMENTS
- DESIGN/EFFECTIVENESS STUDIES
  N_z vs W/S vs T/W - FUTURE
  F 15/F 16 DERIVATIVES

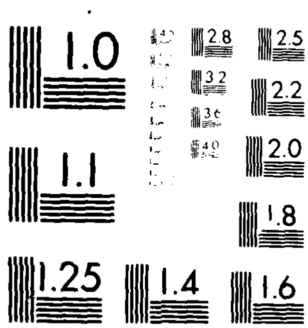


GP76 0192 10
HG 548

AD-A097 285 NAVAL AIR TEST CENTER PATUXENT RIVER MD F/G 5/8
ADVANCED AIRCREW DISPLAY SYMPOSIUM (3RD), 19-20 MAY.(U)
1976

UNCLASSIFIED NL

4 5



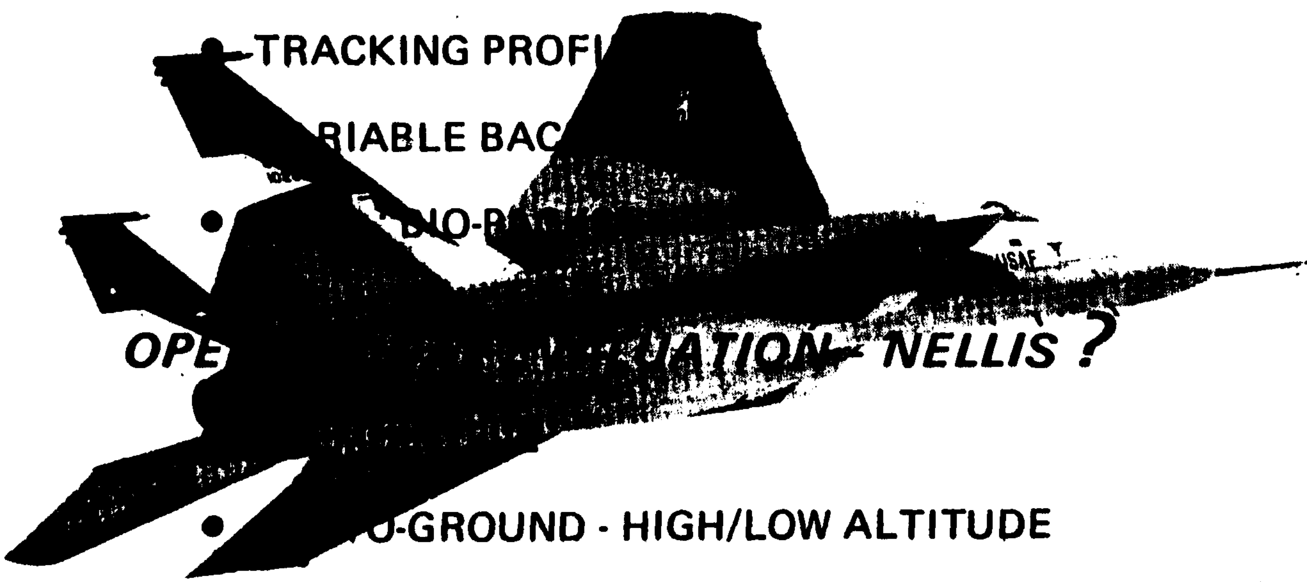
MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

TF-15 FLIGHT SERIES

4 USAF (JTF/OT&E)

PHYSIOLOGICAL COMPARISONS - EDWARDS



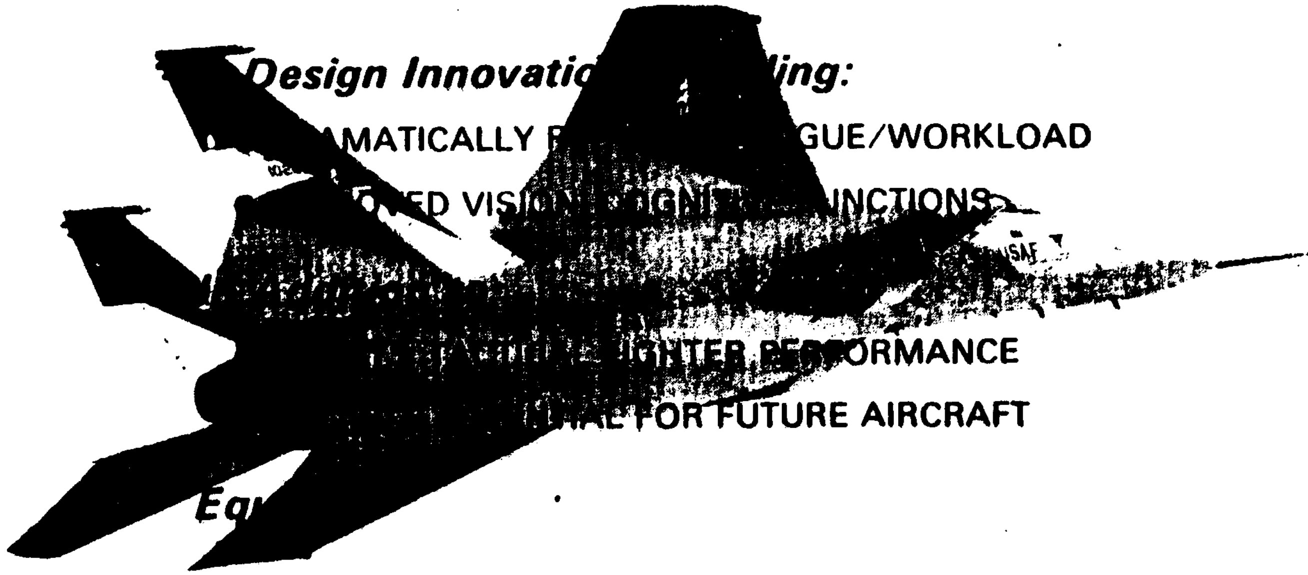
- TRACKING PROFI
- RIABLE BAC
- DIO-B

OPE UATION - NELLIS ?

- O-GROUND - HIGH/LOW ALTITUDE

HAC

FORMULA FOR THE FUTURE



Design Innovatio... ...ing:

...MATICALLY R... ...GUE/WORKLOAD

...OVED VISION... ...UNCTIONS

...IGHTER PERFORMANCE

...FOR FUTURE AIRCRAFT

Eq...

A MAJOR ADVANCE IN CURRENT CAPABILITY AND GROWTH POTENTIAL FOR FUTURE SYSTEMS

. . . . starting with the pilot

SOLID STATE HELMET MOUNTED DISPLAY AND HEAD POSITION SENSING SYSTEM

by: J. Campbell
I. F. Cooper

Flight Automation Research Laboratory
Marconi Elliott Avionic Systems Limited
Rochester.

INTRODUCTION

The Marconi-Elliott Helmet System comprises a Helmet Mounted Display (HMD) and a Helmet Optical Position Sensor (HOPS). This system provides a powerful aid for extending the capability of the pilot by means of designating a ground target, slewing sensors such as IR, LLTV, and radar, or guiding a missile by simply looking in the required direction.

The Helmet Mounted Display used independently provides a highly effective system for displaying warnings and some types of flight control data. In this new form of Helmet Mounted Display a moving display is generated on an array of Light Emitting Diodes (LED) and as with a conventional HUD, is focussed at infinity, so that information or instructions are over-laid on the outside scene. The display incorporates a novel form of optical design which requires only two components - a prism and a combiner.

This paper describes the Helmet Optical Position Sensor System and the prototype Helmet Mounted Display manufactured by Marconi-Elliott for the Pacific Missile Test Center, and in a later presentation Lt. Cmdr. Moroney USN will describe the application of the Helmet Display in an energy management role.

THE HELMET MOUNTED DISPLAY

The Marconi-Elliott Helmet Mounted Display is a logical extension of a successful range of aircraft-mounted head-up displays, where information is presented in graphical form to the pilot by the superimposing of a collimated display onto his real-world field of view. An aircraft mounted HUD has to have sufficiently large optical system to enable the pilot to move his head and scan his forward view whilst ensuring he never loses any of the vital information being presented to him.

The field of view however is inevitably centered about the aircraft longitudinal axis and even with the most advanced optical design the field of view is most unlikely to include areas more than 30° from this axis.

By mounting the whole display on the helmet the field of view is immediately extended to the full limits of the pilot's head movement and the optical system need only be large enough to cope with the relative motion between the pilot's head and his helmet, typically less than 0.6 inch even for high - g maneuvers.

Figure 1 shows how the display has been incorporated into an APH-6 helmet shell with a minimal effect on the external appearance and protective capability of the helmet. The very compact arrangement of the Helmet Mounted Display is made possible by the use of an advanced LED array and the novel optical design. The general layout of the components

within the helmet can be seen in Figure 2 and the Optical System is shown in Figure 3. The LED array and the prism are fitted to a simple but rigid aluminum mounting set into the only significant cut away made into the original shell. The aluminum mounting maintains the structural rigidity of the original shell in this area and ensures the optical alignment of the system.

The prism is pivoted so that it can be rotated to retract into the helmet shell to facilitate donning the helmet, although it has been found that this is not strictly necessary due to very small size of the prism. The compactness of the prism also prevents intrusion into the pilot's field of view.

The LED array is shown in Figure 4 and is only 0.3" square and is mounted on a header 0.75" diameter and of similar length. It comprises a matrix of LEDs on a 10 thou pitch and it is the compactness of this device which is the key to the design of this helmet mounted display. The display is red at a wavelength of 650 nm.

This LED array has been manufactured by the Hirst Research Centre Laboratories of The General Electric Company Ltd. as part of a development program started a few years ago with the objective of producing high brightness, high resolution LED arrays for use in airborne displays.

An earlier stage in the development was the manufacture of arrays in which the format to be displayed was fixed at the design stage and the user had the flexibility only of being able to select which parts of the display were to be illuminated. These displays have been used in helmet mounted displays but the limit of their application is probably reached when the area required for connection to the drive circuits exceeds that of the display. A reasonable maximum for display content in this format is shown in Figure 5 - in which each of the 72 separate elements is discretely addressable.

To overcome the limit imposed by connections, it is necessary to adopt some form of matrix interconnection and the array used in this helmet is the first application of this technique. The specified array comprises 460 matrix points and 21 discretely addressable segments controlled by 65 connections (-only 43 are required for the 460 point matrix).

The individual LEDs in the matrix part of this array are 5 thou square on a pitch of 10 thou. In this particular display, up to 20 diodes may be used in a display format which is repeated at 180 frames/sec at a mean brightness of 1500 ft. Lamberts. These numbers are largely determined by the electronic design chosen to meet the Navy requirement.

The ability to manufacture an array of this type permits a big step forward to be made in the design of helmet mounted displays as it eliminates the weight involved in a CRT solution with its EHT cable or a fibre optic bundle. This alternative technology has a tremendous development potential for the future.

The current performance being achieved by these monolithic LED arrays is:

Brightness	18,000 ft. Lamberts
Life	>10,000 hours to half brightness
Current Density	136A/cm^2

The optical and mechanical layout is shown in Figure 3 which represents an approximately vertical section through the helmet. The LED and the prism are mounted on the aluminum panel which maintains their relative position and provides a location onto which the visor clicks when lowered. Thus the whole optical system is located together. The rays of light emerging from the LED array enter the prism at one face. The prism serves three purposes - it largely corrects the aberration introduced by the off-axis spherical combiner, it folds the optical path into the space available, and its cylindrical surfaces correct astigmatism. The rays emerge from the prism and are reflected by the coating on the inside of the combiner. The curvature of this surface collimates the image and reflects it to the pilot's eye. The exit pupil of the optical system is a circle 0.7" diameter which means that the entire display can be seen when the eye is at any point within this circle. This large exit pupil means that the fitting of the helmet to the pilot is relatively un-critical and accomodates helmet movement due to 'g'.

In this helmet the combiner was required to be fitted to the neutral density visor so the coating was chosen to provide a transmission equal to that of the visor and a relatively high reflectance to the LED image so there is little difference in the outside view seen by each eye.

It should be noted that this helmet was constructed as a prototype to evaluate the design principles involved for a particular application. In the light of the experience with this prototype it is possible to set out the next development steps.

Improvement areas are -

(i) the reduction of weight by the use of custom-designed integrated circuits instead of the present printed circuit boards using off-the-shelf components for the Array Drive Electronics.

(ii) introduction of entirely plastic optics equivalent to the present glass prism to enhance the helmet's safety and also reduce weight.

The continuation of the GEC and Marconi-Elliott programs will of course include the areas in which development is still required - in particular there can be some improvement of the optical design to reduce the remaining aberrations at the same time as refining the production version of the visor design to include the combiner element in a one piece visor free from optical distortion or obscuration at the edge of the combiner. In the prototype helmet display it has been necessary to remove the clear visor in order to obtain sufficient mechanical clearance for the components necessary to modify the existing neutral density visor - the

clear visor will be restored when the production purpose-built one-piece visors are fitted.

The major breakthrough in the design of this Helmet Mounted Display has been the construction of the monolithic LED array and the vital technology has now been developed. Clearly there is a long way to go before the resolution of a CRT is approached but it is theoretically possible that this could be done with LED arrays. Diodes of the small size required, about 1/2 thou square, have been made and techniques exist which may enable the matrix connection pattern to be established. The development problems with drive circuits will take some time to solve. In the more immediate future, say 2 years, we expect to be able to manufacture LED arrays 2-3 times finer than included in the present helmet. A helmet incorporating this array will be able to offer a display of 100 x 100 elements which is a very worthwhile step indeed.

THE HELMET OPTICAL POSITION SENSOR SYSTEM

While the HMD above can provide the pilot with much useful information and guidance the full potential in the weapon aiming role cannot be achieved without the Helmet Position Sensing System.

The basic properties sought in the Helmet Position Sensing System were:

SOLID STATE - Low Complexity and High Reliability
HIGH ACCURACY Over Wide Angle Coverage
HIGH SAMPLING RATE

Electro-optical technology offered an excellent all round potential and the Marconi-Elliott Helmet Optical Position Sensor (HOPS) development has been based around a simple 'V' slit camera incorporating a high resolution linear CCD array (Charge Coupled Device).

Helmet roll, pitch and yaw angles are sensed by this cockpit-mounted V slit camera viewing three LEDs on the side of the helmet. The lower two LEDs are arranged to be parallel to the pilot's line of sight through the helmet sight. Figure 6 shows the basic arrangement.

Three LED rays in space are determined by the camera, referenced to its optical axis. The computer performs a 3-dimensional "fit" of the LED triangle (of known size) into the frame contained by the three LED rays. By using the previously computed position a "fit" is quickly and accurately obtained from this starting point. The LED position in space are then computed, from which helmet roll, pitch and yaw angles are obtained.

Increased helmet rotational coverage is achieved by using a further LED set mounted on the other side of the helmet, and another camera on the other side of the cockpit. A combination of LED sets and cameras enables 360^{o} yaw coverage to be achieved by switching within the computer to the appropriate camera viewing a complete LED set.

The HOPS system (shown in Figure 7) comprises the following basic units:

(1) V SLIT CAMERAS (2 off)
(2) HOPS ELECTRONIC UNIT

These basic units are described below:

The V Slit Camera

The basic construction is shown in Figure 9.

Light from the helmet-mounted LED passes through the narrow 0.008" V slip and a V image is formed across the CCD. The CCD consists of 1728 photosensitive elements and the points at which the V image crosses the CCD is clearly defined in the CCD electrical output. Movement of the LED results in movement of the V image and the CCD waveforms shown in Figure 8 clearly show the CCD output resulting from yaw and pitch movement of the LED.

The camera actually determines the direction cosine of the LED with respect to its optical axis, and the accuracy achieved is limited only by the geometry of the V slit and the CCD. As these are produced by photolithographic methods and no refractive optics are involved, the basic accuracy is extremely high.

The V slit camera is unique in its ability to sense two degrees of freedom with a single CCD array, and this results in a camera with low optical and electrical complexity giving the very desirable features of:

HIGH RELIABILITY
HIGH ACCURACY
LOW COST
COMPACTNESS

The HOPS Electronic Unit

The Helmet LEDs are switched cyclically in sequence from the HOPS Electronic Unit.

The V slit camera first samples and stores the helmet background with the Helmet LEDs switched off to establish the pattern of background illumination, which may include direct sun. This is used as the basis for recognizing and extracting the wanted image from LEDs 1, 2 and 3.

The V slit camera now samples the helmet with the LEDs emitting in turn, and the CCD output is subtracted from the background pattern to give clearly defined LED pulses.

The effect of a LED signal being extracted from a much larger superimposed sun signal by this correlation process is shown in Figure 9.

The data is now in the form in which the peaks of the two LED images can be determined. This is done digitally by using the LED pulses in the CCD output waveform to gate counters.

These six binary numbers (two per LED) are output via the interface circuit in the HOPS EU to the computer which carries out the line-of-sight (LOS) computation.

The rate at which LOS data can be output to the aircraft weapon system is limited only by the clock rate of the CCD and the iteration rate of the associated digital computer. The designed CCD clock rate is 2.5 MHz which results in a signal sample time of 1.5 milliseconds. With a representative weapon aiming computer the LOS computation output data rate is 50/second.

This means that even with any data rate reduction which results from special purpose digital filtering the performance of the system will be limited only by the physical tracking rate ability of the pilot.

The system can be configured to interface with any other aircraft system with either digital or analogue interfaces.

Tests conducted on a prototype HOPS system have demonstrated that the system meets parameters and accuracies given in the summary specification. This accuracy is entirely adequate when considered in relation to other system errors of the complete helmet aiming system.

These errors arise from:

(1) Pilot ability to track and mark a target to no better than 1° to 2° under the vibration experienced due to buffeting in high speed flight at low altitudes.

(2) Optical distortion caused by the canopy, especially at acute angles. This error can be up to 2°.

(3) Error in measuring Head Position. Less than 0.5°.

The resulting system design is fully solid-state. The cockpit-mounted camera is only 2 1/4" diameter by 2 1/2" long and the LED set adds negligible size and weight to the Helmet. The EU can be mounted in the aircraft equipmentbay and interfaced with a time-shared or dedicated computer depending on the application.

The current size of the HOPS EU is a 1/2 ATR Short box, but this will be reduced in the production unit which uses custom hybrid/LSI component types.

To summarize, the HMD and HOPS together form a compact and versatile system for use in fixed wing and helicopter aircraft to provide display and weapon or sensor aiming capability. The system is novel in concept and has been shown to be fully practicable with considerable development potential.

ACKNOWLEDGEMENT

The authors would like to thank the Directors of Marconi-Elliott Avionic Systems Limited for permission to read this paper.

Particularly they would like to record their appreciation of the contributions made by their colleagues in the Flight Automation Research Laboratory, by Mr. S. M. Ellis and by Dr. D. Wickenden of the Hirst Research Laboratories.

SUMMARY OF SPECIFICATION

HELMET OPTICAL POSITION SENSOR (HOPS)

Range of head movement	- lateral - $\pm$ 4 inches
	- longitudinal - $\pm$ 6 inches
Angular range of head movement	- Yaw - $\pm$ 180^{o}
	Pitch - $\pm$ 70^{o}
	Roll - $\pm$ 20^{o}
Accuracy	- $1/2^{o}$CEP (depending upon installation)
Weights	- Helmet installation 1 oz.
	Cockpit optical sensor installation 14oz
	HOPS Electronic Unit 1/2 ATR Short,
	15 lbs.
	Pilot's Controller 8 oz.
Power consumption	- 100 W

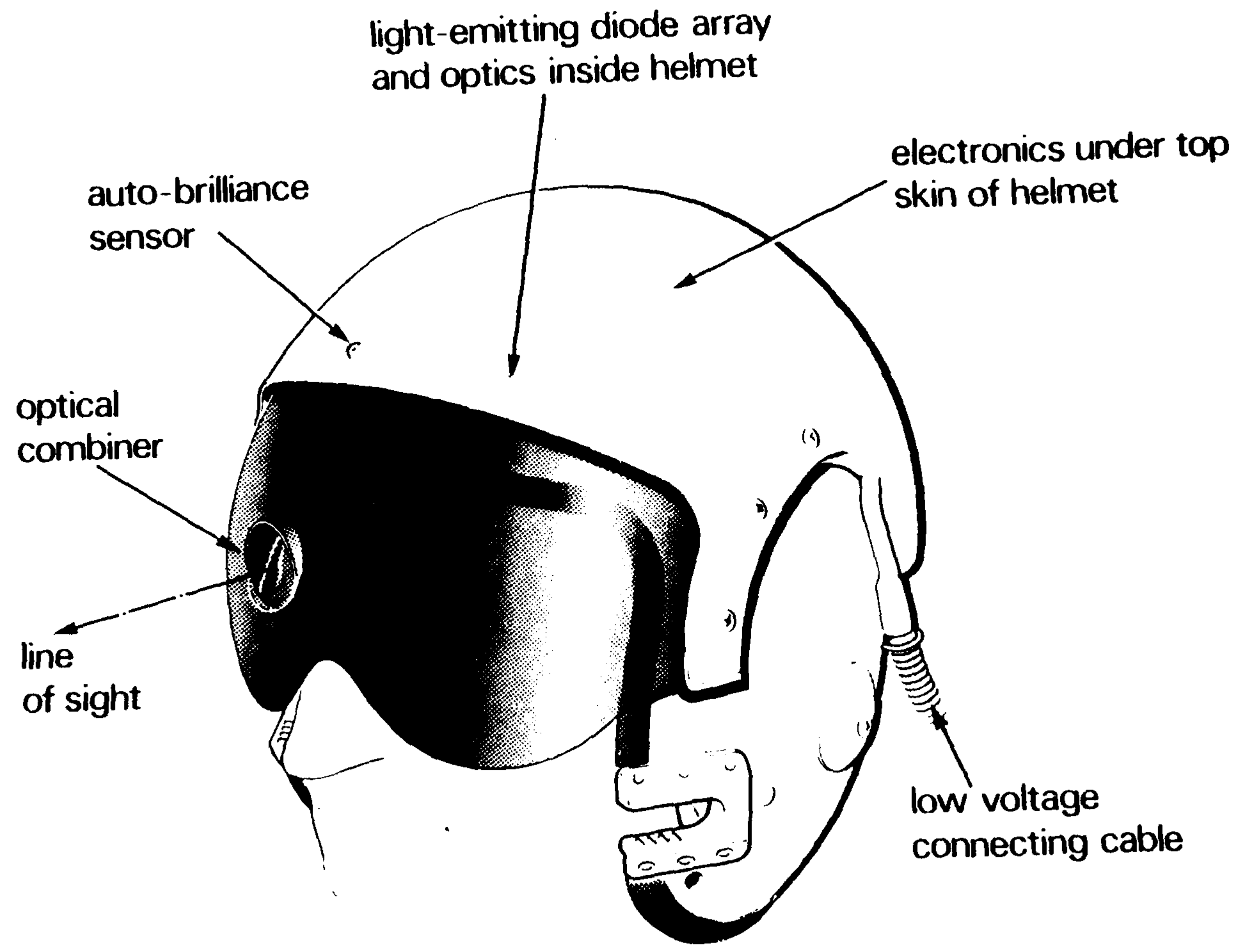


Figure 1 U S Navy APH-6 Helmet Incorporating Prototype Display

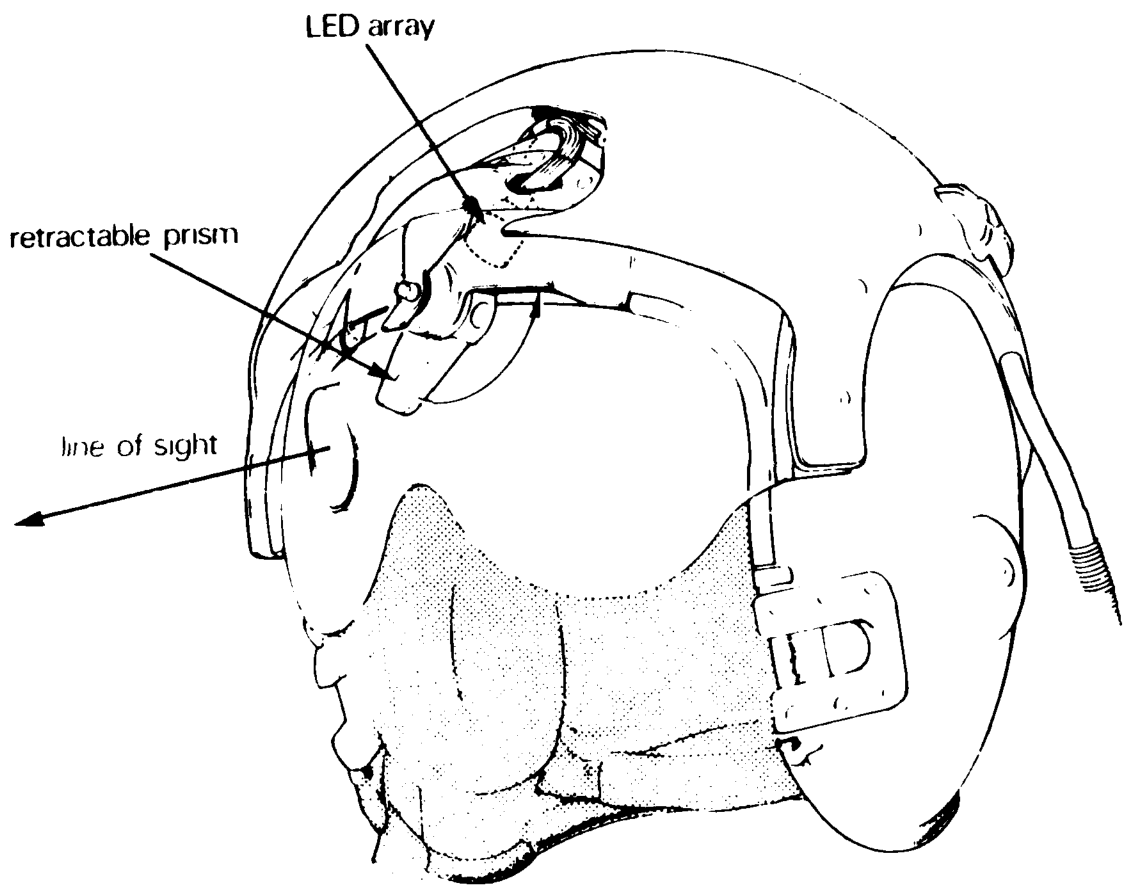


Figure 2 Helmet Mounted Display System

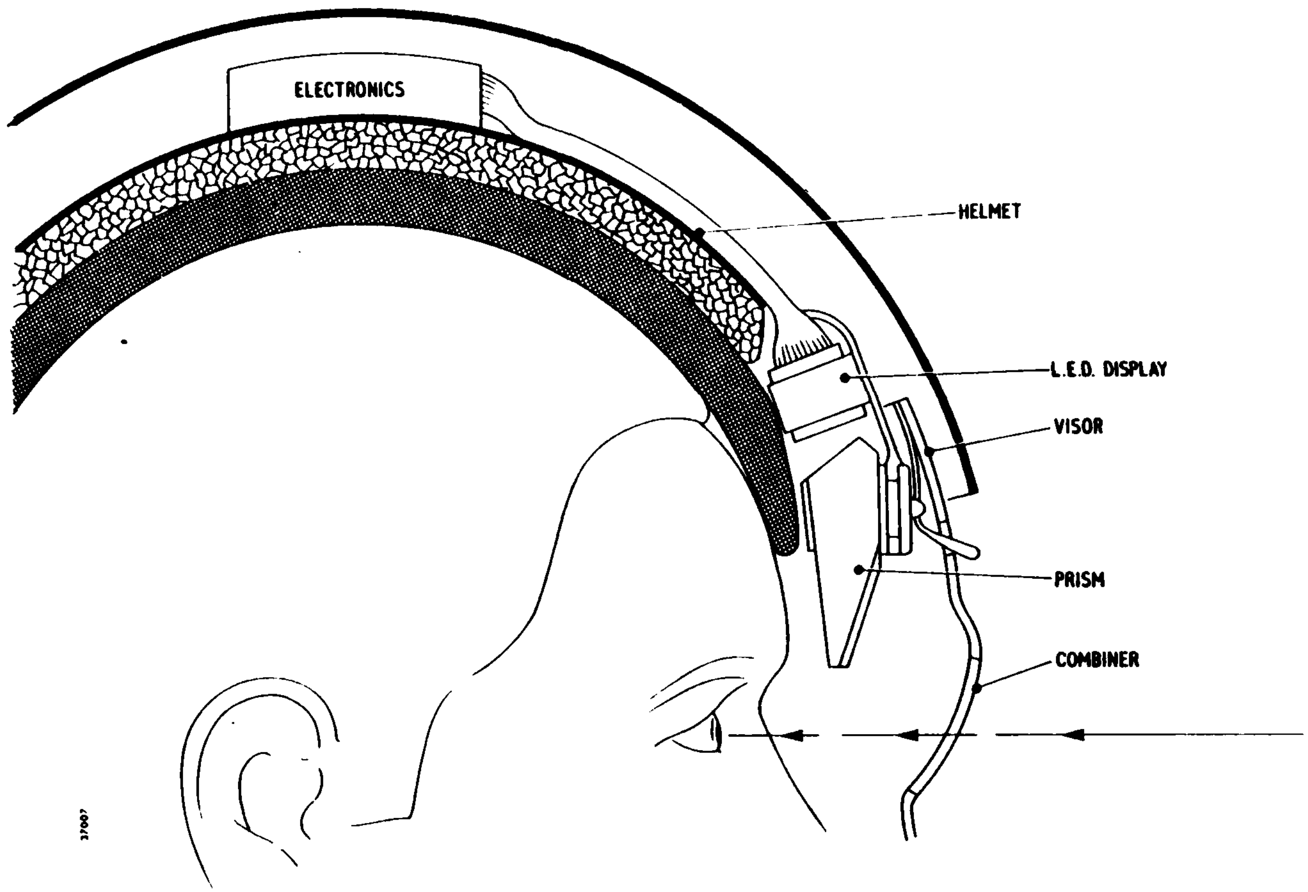


Figure 3 Schematic Layout of Prototype HMD

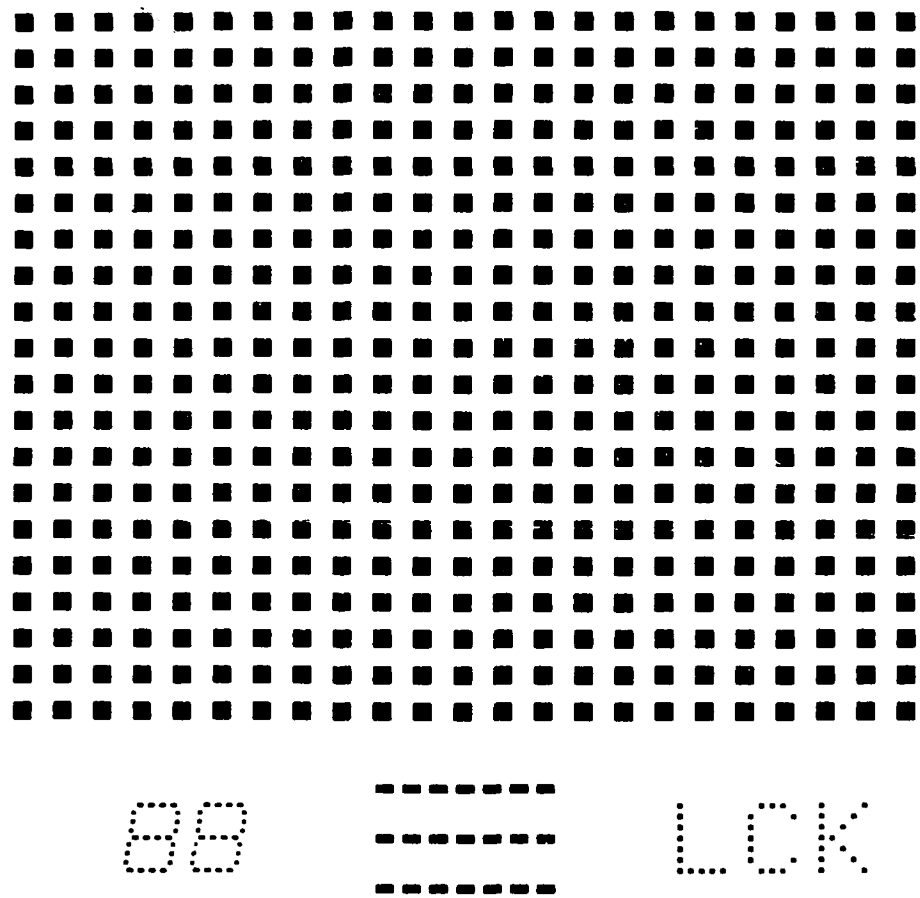


Figure 4 Led Array Fitted to Prototype HMD

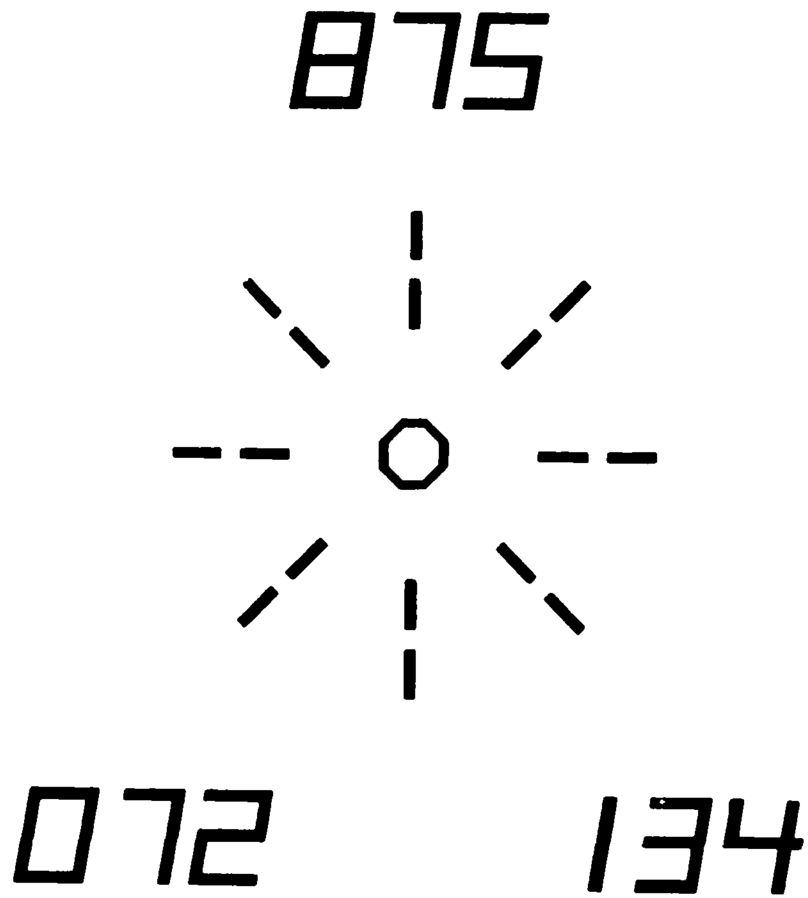


Figure 5 Typical Fixed Format LED Array

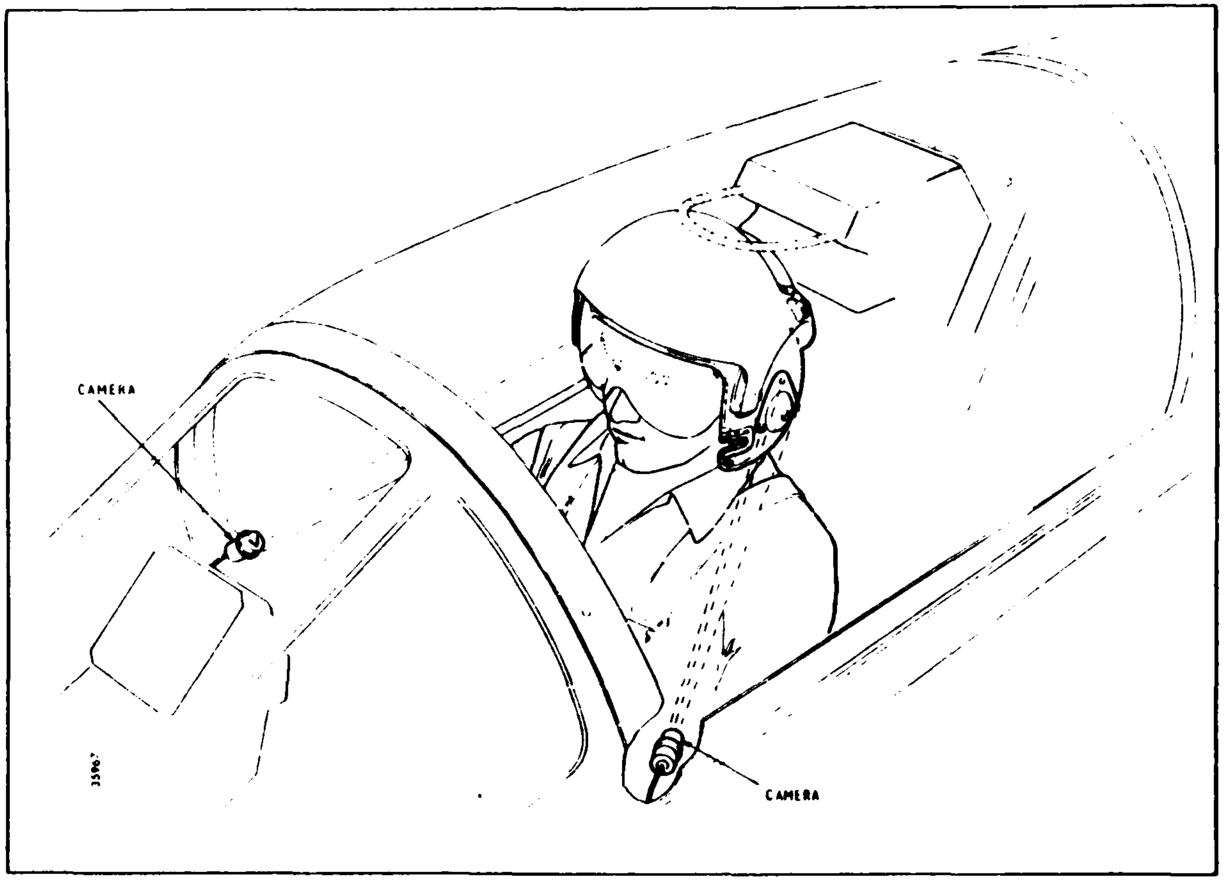


Figure 6 Helmet Optical Position Sensor System (HOPS)

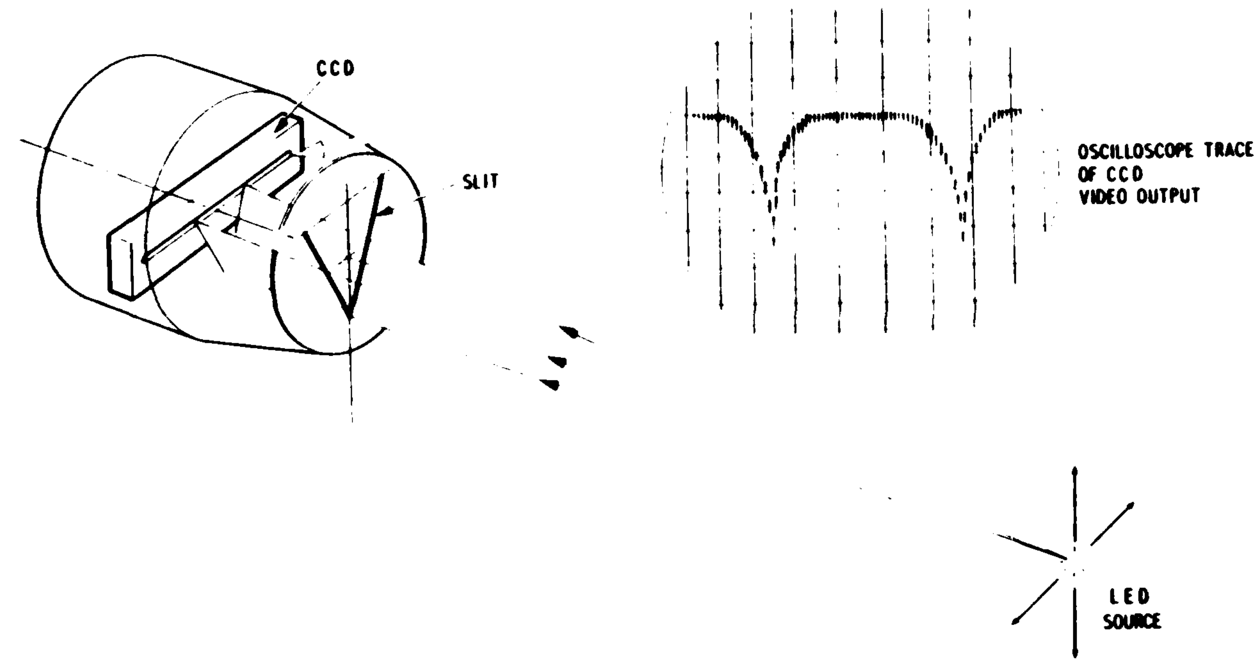


Figure 7 V-Slit Camera for HOPS

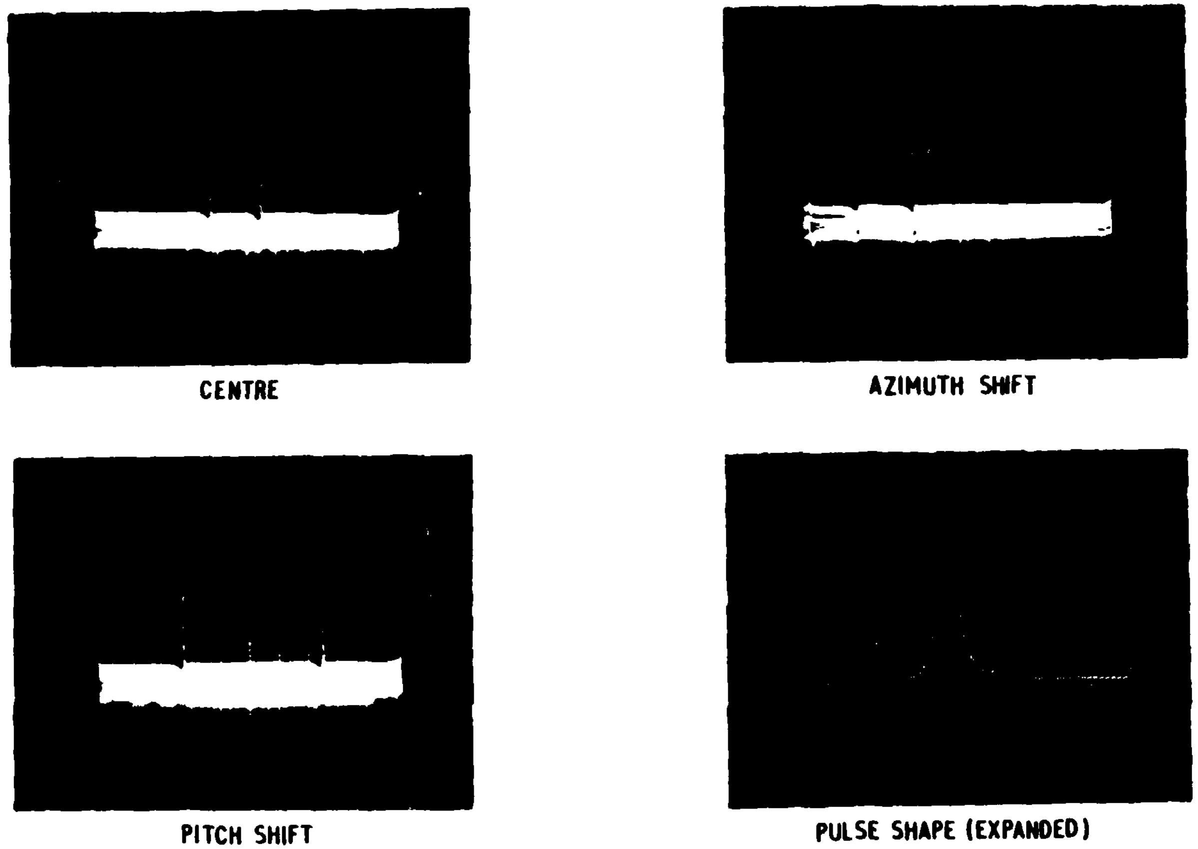


Figure 8 CCD Oscilloscope Waveforms

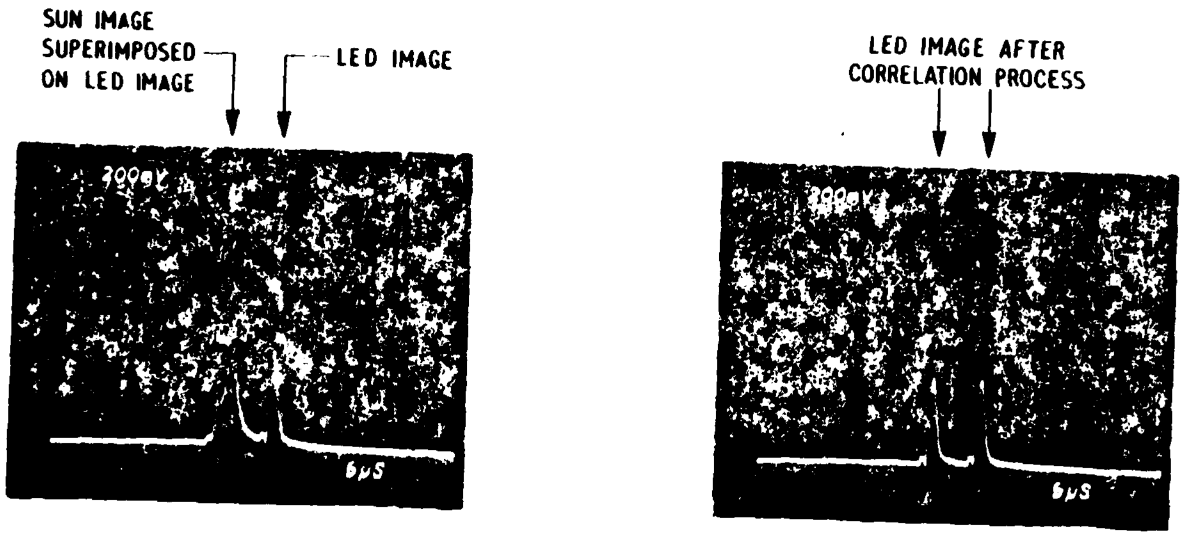


Figure 9 Oscilloscope Waveforms Showing Sun Image Rejection

A HELMET-MOUNTED LIGHT EMITTING DIODE (LED) DISPLAY APPLIED TO THE AIRCRAFT MANEUVERABILITY PROBLEM

LCDR William F. Moroney MSC, USN
LCDR Penn E. Mullowney USN

Pacific Missile Test Center
Point Mugu, California

ABSTRACT

The Pacific Missile Test Center (PACMISTESTCEN) has procured a Helmet Mounted Display (HMD) which uses a Light Emitting Diode (LED) Array as the display medium. The HMD, developed by Marconi-Elliott Avionic Systems, LTD will be used to present an energy maneuverability display format similar to that developed by McDonnell-Douglas Aircraft Company. This paper describes the need for and potential uses of such a display. Use of this display is expected to allow pilots of new high energy aircraft to maxamize the performance capabilities of their aircraft.

BACKGROUND

During the 1975 Advanced Aircrew Display Symposium RADM J. S. Christiansen USN (ret) then was the Assistant Deputy Chief of Naval Operations, Air Warfare addressed the needs of fighter pilots. He stated "As a fighter pilot ... I want to know how much (aircraft performance) I've got left and I need it (the information) where I can see it." The display system to be described herein is believed to meet these requirements.

By way of introduction, some background information is appropriate. Pruitt (1974) has defined energy maneuverability (EM) as: the ability to perform a change, or a combination of changes, in direction, altitude and airspeed expressed in terms of energy and energy rate. Pruitt distinguishes three types of conditions in Air Combat Maneuvering (ACM):

(1) Defensive - This pilot leads the engagement and for the most part engages in energy loss maneuvers since his performance is characterized by a series of turning maneuvers.
(2) Neutral - A stand-off conditions where each pilot waits for the other to make a mistake or one pilot utilizes his energy capability to gain the offensive.
(3) Offensive - Under this condition the pilot reacts to the defender for turning, speed/altitude control and maintains an energy level near that of the defender while attempting to maintain a positional advantage at some range and range-rate.

The common thread to all these conditions is that the pilot is concerned with his energy state in all the phases of ACM.

MAXIMIZING MANEUVERABILITY CAPABILITY

Let us examine some critical elements associated with maximizing maneuverability capability:

(1) Training opportunities are limited - increased fuel/maintenance cost have increased training cost thus todays fighter pilot can expect less "seat-of-the-pants" experience in ACM.
(2) Lack of essential information - essential information is not available or if it is available it is not useable due to inappropriate format or display location. The quality fighter pilot is an individual who is one with his machine, i.e. he integrates altitude, "g", airspeed, angle of attack with the feel and sounds of the aircraft. He creates, in his head, the V-N diagram (a V-N diagram describes the performance capability of an aircraft in terms of load factor "g" and velocity) or parts of the V-N diagram and, as accurately as possible locates his aircraft in that diagram. Efforts have been made to present V-N information to pilots but in most cases they did not progress beyond the simulator stage or if they were flown, the data were presented on cockpit displays or on the heads-up display (HUD). Unfortunately the target is frequently not off the nose so HUD utilization in ACM is severely limited.
(3) Differences in present and new generation fighters - Because of the high thrust to weight ratios and the low wing loadings of the new generation of fighters in particular the F-16 and F-18 tomorrow's fighter pilot can gain or lose energy at a much faster rate than for present operational aircraft. The evolution of strakes, slots and lifting body fuselages provide much more subtle cues of aircraft performance than are available with todays aircraft. Because of the subtle nature of these cues, we can expect our new generation of fighters to be inadvertently overstressed and/or their capability not maximized in ACM.
(4) Differences in aircrews - In ACM the requirement is eyes-out-of-the-cockpit with a rare glance inside until the target is off the nose. The F-4 pilot had a Radar Intercept Officer (RIO) or Guy-in-Back (GIB) to provide altitude/airspeed and weapon status information when needed. However pilot's of future fighters will be flying single seat aircraft. Thus, the pilot's need for performance information is increasing while the sources of such information are decreasing.

WHERE, HOW, WHAT TO DISPLAY

Having seen the need for an energy maneuverability (EM) display, the questions to be addressed are "where, how and what to display?"

WHERE SHOULD EM DATA BE DISPLAYED? This question was the easiest to answer. Indeed the answer was simplistic, "Put the display where the

pilot can see it". To us, that meant keeping the display before the pilot's eyes at all times by projecting the EM data on to the pilots visor. Thus, the pilot could see the display and his target or pursuer simultaneously.

HOW SHOULD THE EM DATA BE DISPLAYED? A description of the technical aspects of the display is contained elsewhere in this document in a report by J. Campbell and I. F. Cooper (1976) of Marconi-Elliott. However, some additional comments are appropriate. In developing this display system special efforts were made to:

(1) Limit weight - as currently configured the display, prism and electronics have added approximately 12 ozs to the APH6 helmet with a dual visor. This weight increase can be easily reduced to 6-9 ozs by utilization of custom designed integrated circuits, plastic prisms and a special visor.
(2) Limit bulk - the prototype helmet is the basic APH6 with the clear visor removed. Development of a special visor and a smaller electronics package would reduce the bulk of the APH6 helmet and allow for a smaller visor cover.
(3) Provide for adequate brightness - existing helmet mounted displays are often not visible in the high ambient light found at altitudes. A preliminary evaluation of this LED display however indicates, that the display is visible to within 10^{o} - 15^{o}s of the sun. This visibility may be attributed to:

    (a) the large amount of energy delivered to the pilot's eye and
    (b) the color contrast provided by the use of a red LED. The latter effect is attributable to the color, red, which does not usually appear in the airborne environment and therefore provides good color contrast with the sky's white, blues and grays, and with the earth's browns and greens.

(4) Provide a large exit pupil - all helmet mounted displays have an area on which the image is projected and through which the pilot must look in order to see the display. This area is known as the exit pupil. The fairly large exit pupil (1.25 inches in diameter) associated with this display system combined with the form fit liners assures that the display will always be available to the pilot.
(5) Avoid reduction of visual field - a display mounted on tube attached to the side of the helmet was briefly considered, but the loss of peripheral vision was not acceptable. Ultimately it was determined that the display should project down from the top of the helmet. As presently configured the display/prism support system on the prototype helmet slightly reduces the pilots upward vision in one eye. However, the size and shape of the support system can be reduced and this problem will be eliminated.
(6) Facilitate free head movement - nine thin wires link the display system to the controller, which converts aircraft parameters into the display format to be described later. These nine wires fit into a cable slightly thicker than the

earphone cable presently in use on aviators helmets. This, in addition to safety, is one of the advantages of using a display with a low power requirement.

WHAT EM DATA SHOULD BE DISPLAYED? After reviewing a number of energy management/maneuverability display formats which had been tried previously a format described by Ralph Pruitt (1974) of McDonnell Douglas, was selected as the most promising. Pruitt selected the basic V-N diagram (figure 1) and modified it so that areas of energy loss and energy gain were contained within the figure (figure 2). This format has received considerable use in simulations at the McDonnell Douglas Corporation, St. Louis facility. However, the authors considered the format to be too complex to be compatible with an on-the-visor presentation.

Fig 1: BASIC V-N DIAGRAM

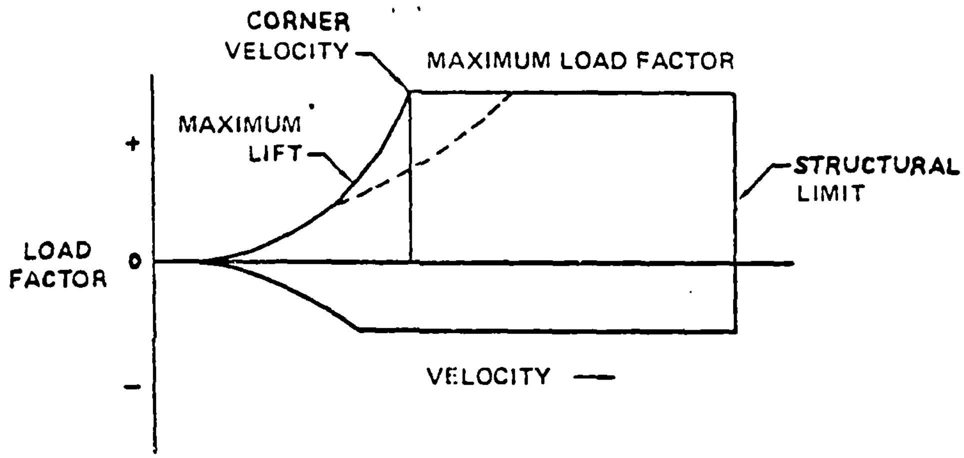
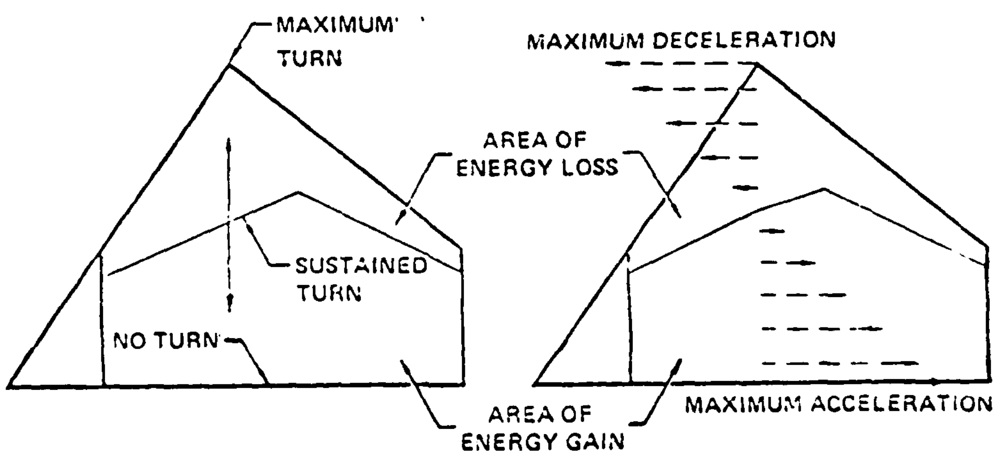


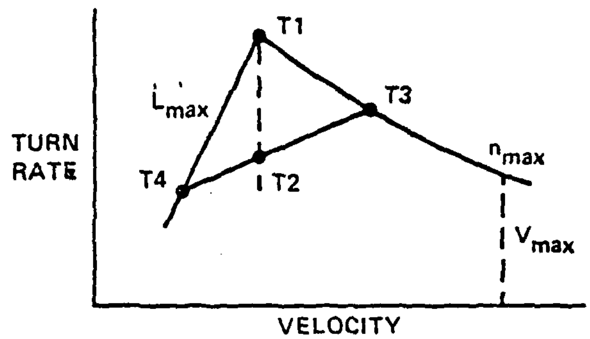
Fig 2: MANEUVER TRIANGLE TRENDS



Therefore, a format based on figure 3 which describes the key turning conditions, was selected for the purposes of an helmet mounted energy maneuverability display, points T1, T3 and T4 were considered cirtical. Together these points define the generic energy management display described by figure 4. To the minimum sustained turn radius (T4) point, Corner Velocity (T1) point, and maximum sustainable turn rate (T3) point a new data point has been added - aircraft present state. It should also be noted that in this format "g" is plotted against calibrated air speed (CAS).

Fig 3: KEY TURNING CONDITIONS

TURN RATE VERSUS VELOCITY



n_{max} – MAXIMUM STRUCTURAL LOAD FACTOR

L_{max} – MAXIMUM USEABLE AERODYNAMIC LIFT (MAXIMUM ANGLE-OF-ATTACK)

V_{max} – PLACARD SPEED

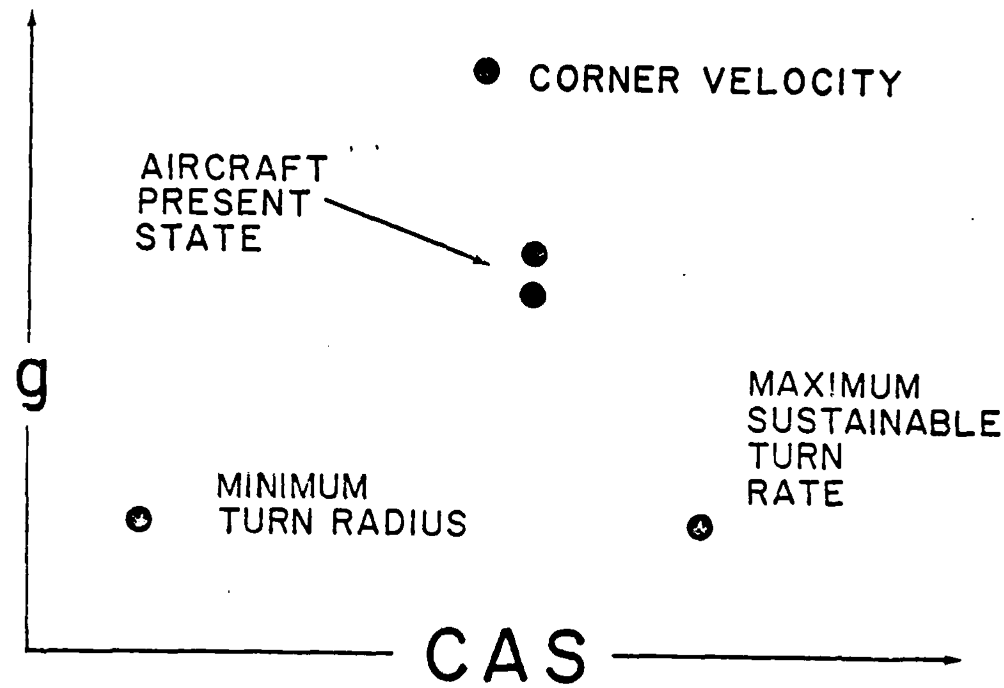
T1 – CORNER TURN, n_{max} AND L_{max} (MAXIMUM TURN RATE POSSIBLE)

T2 – MAXIMUM SUSTAINED TURN RATE AT VELOCITY FOR CORNER TURN

T3 – MAXIMUM SUSTAINED TURN RATE

T4 – MINIMUM SUSTAINED TURN RADIUS

Fig 4: CONCEPTUAL EM FORMAT



In utilizing this display a pilot decides which point he wishes to fly to and then gets his aircraft there in whatever manner he considers appropriate (e.g., to accelerate he may dive or apply power or both). What his display will show is a movement in his aircraft present state symbols and its position relative to the performance boundaries of the aircraft.

EVALUATION OF THE DISPLAY SYSTEM

Laboratory tests will be carried out at PACMISTESTCEN and Aerospace Medical Research Laboratory (AMRL) to ascertain the performance of the component parts of the display system. In addition, laboratory testing will be carried out on the entire system to determine subsystem compatibility and total system performance characteristics. Primary human factors considerations concerning brightness levels, symbology, resolution, etc., will be explored during the laboratory testing phase. The electronic components will be subjected to environmental tests (vibration, pressure, and temperature) representative of the test environment.

Tentatively the display system will utilize United States Air Force (USAF) Instrument Flight Center (IFC) T-38 airplanes for this testing phase. Acceleration effects, resolution, field-of-view, and information retrieval are some of the human factors which will be addressed. Additionally, system capabilities in an actual maneuvering environment will be determined during approximately 120 hours of T-38 flight testing. Inflight tests will require subject Air Force pilots to perform maximum turn rate (instantaneous and sustained), minimum sustained turn radius, maximum

energy gain, energy sustenance, and maximum energy climb maneuvers. Performance comparisons between maneuvers performed with and without the HED will yield a preliminary assessment of the system's potential in augmenting tactical performance of fighter aircrews. It is expected that pilots equipped with the display will fly the T-38 closer to the performance limits of the aircraft than pilots who do not have the display. Results and recommendations from the laboratory and flight tests will be published in a joint Navy-USAF report.

OTHER USES FOR THE DISPLAY SYSTEM

Because of the flexability associated with matrix displays, a wide variety of information could be presented on the visor. However, considerable caution needs to be exerted in selecting both the information to be displayed and the display format. The information to be displayed should be limited to information which is needed when the pilot is flying with his eyes out of the cockpit but cannot or may not be displayed using the HUD. Thus, this display system might be used in conjunction with a tail warning receiver or to designate or locate air or ground targets in a lead position sensing system (this would be a necessity with off-boresight weapons). The present display system is not a mini-HUD, but it could be used to expand HUD's potential.

REFERENCES

1. Campbell, J. and Cooper I.F. Solid State Helmet Mounted Display and Head Position Sensing System.
2. Pruitt, V.R. Within Visual Range Energy Management Display: McDonnell Aircraft Company Report A3504 of 20 October 1974.

ACS 11,213

DISPLAY TECHNIQUES
FOR
AERIAL GUNNERY

by

C. H. Ide

Presented at:

Third Advanced Aircrew Display Symposium
Naval Air Test Center
Patuxent River, Maryland
May 19-20, 1976

GENERAL ELECTRIC

AIRCRAFT EQUIPMENT DIVISION
BINGHAMTON, NEW YORK

PREFACE

This paper has been prepared for the Third Advanced Aircrew Display Symposium sponsored by the Naval Air Test Center, Patuxent River, Maryland, May 19-20, 1976. Its purpose is to focus on potential improvements in aerial gunnery which can be achieved through the use of flexible CRT HUD display formats. The ideas projected by this paper suggest that the development of gunnery algorithms and symbology cannot be done at a superficial level, but must stem from analysis, simulation, flight test, and in-depth integration into particular production avionic systems. This thesis clearly applies to many other operational functions which drive other portions of the total cockpit display formats.

INTRODUCTION

Although the use of a gun or "cannon" takes place in a brief segment of the Air Combat Maneuvering scenario, its capabilities are complementary to current missiles. In many cases, the gun has produced kills at short ranges below the fuzing limit of an IR missile or during the follow-up to an errant missile shot. The characteristics of the gunsight mechanization, including dynamic performance of the aircraft and its flight control system, have a definite effect on the useful combat envelope of the gun. This envelope can range from the limited but classic "six o'clock" position at 1,000 feet, to positions 120^{o} angle-off with firing ranges out to 5,000 feet. Achievement of this expanded envelope requires well defined development programs.

The purpose of this paper is to identify the critical aspects of the aerial gunnery problem. It will be shown that gunnery algorithms are evolving through advances in hardware and software technology and that significant improvement in combat performance is possible. The discussion is not mathematical in nature but provides a summary of experience and knowledge of the General Electric Company in this field.

The General Electric Aerospace Controls and Electrical Systems Department in Binghamton, New York, is the current production supplier of flight control systems and gunsights for many military aircraft. Over 10,000 Lead Computing Gyros and Optical Display Units have been built for F-104, F-4, F-111, F-5E and F-15 aircraft. In addition, a similar quantity of GE flight control systems have been built for the F-4, F-111, F-15, and A-10 aircraft. The experience of designing, testing and producing both control and display systems provides a unique insight into the problems of aerial gunnery. Based on this background, GE has been awarded a series of R&D contracts which address several new concepts

in aerial gunnery. These contracts include the Multimode Flight Control Definition Study (AFFDL-TR-71-39), the Firefly II for automatic flight control using director fire control, and the flight test of the GE Multiple Reference Gunnery System on the Air Force Sight Evaluation F-106 aircraft. These programs are currently creating new symbology requirements which ultimately will impact cockpit display hardware. As part of the development process, the new concepts are being evaluated in the Simulation Facility shown in Figure 1. This GE fixed-base man-in-the-loop aircraft simulation includes aerodynamic, flight control and gunsight functions carefully tuned for study of the precision control task required in aerial gunnery.

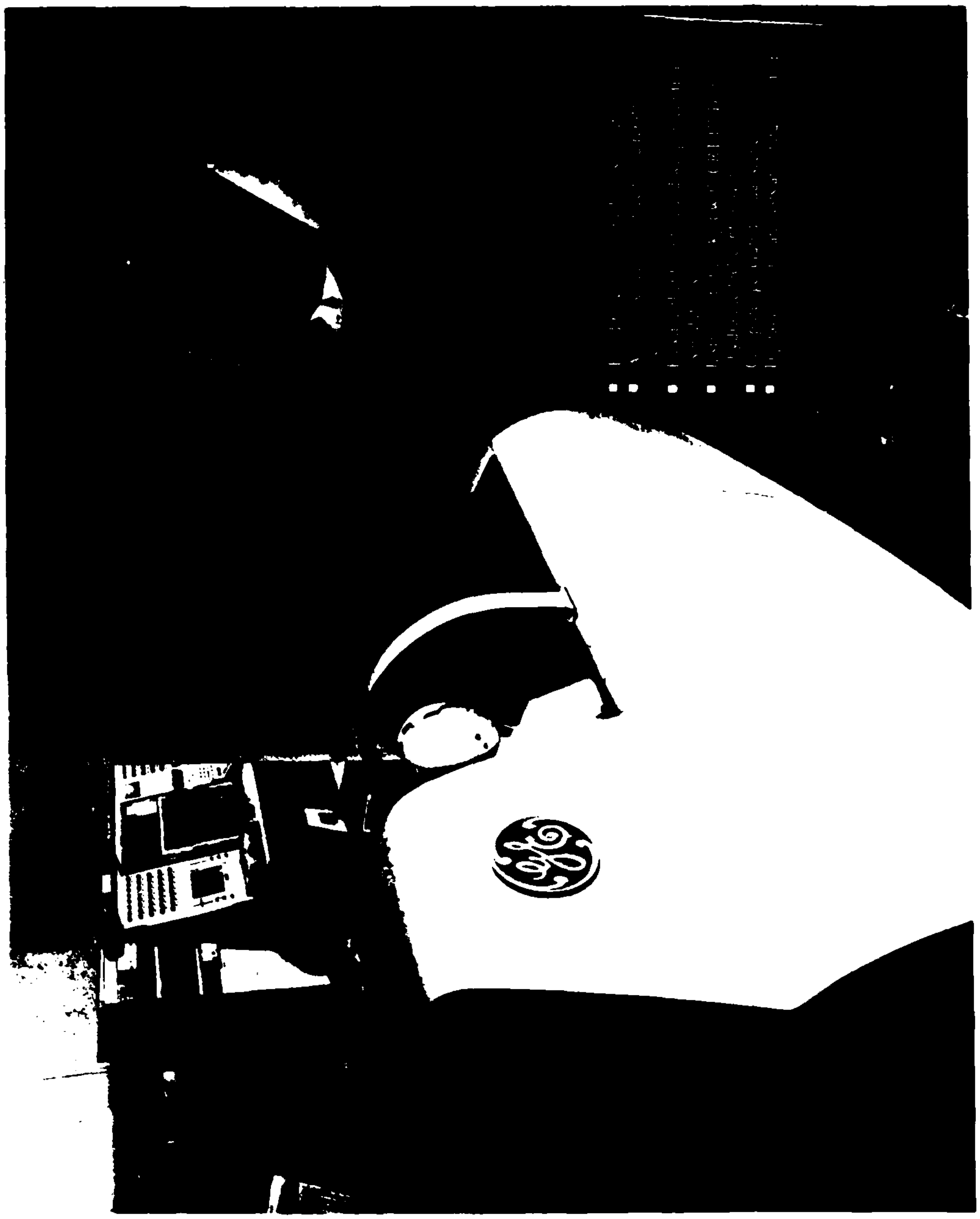


Figure 1.

THE GUNNERY PROBLEM

Effective display techniques for the aerial gunnery must be based on an understanding of the geometric and kinematic relationships of the firing aircraft, the target, and the bullets. To being the discussion of the problem, it is useful to define the Reference Target Concept.

Figure 2 shows the firing aircraft in relation to a target and a gunsight reticle. Regardless of the algorithm used to control the reticle, it can be considered a reference target for which the gun is correctly aimed. This means that one bullet-time-of-flight from when bullets are fired, the reference target will, in concept, be hit by the bullet stream. To hit the real target then, it must also come together with the reference target and the bullets one time of flight after firing. The visual relationship observed by the pilot is shown in Figure 3. A vector triangle exists between the instantaneous gun line, the reference target (reticle) and the real target. When the reference target and real target appear to be converging, the pilot must fire one time of flight before they intersect. This is the process of snapshooting. Tracking solutions are a special case where the relative visual velocity is zero. Snapshooting can be used with a reticle based upon any fire control algorithm and thus the reference target concept can be applied to any gunsight mechanization. One comparison of different gunsights then is a matter of how good a reference target they represent in a particular combat situation.

Before considering the different gunsight options, we should look at the primary parameters of the gunnery problem. They are: range, target motion, own aircraft motion, gravity, muzzle velocity, and bullet drag. These factors require that the gun be pointed ahead of the target by the lead angle shown in Figure 2. This angle in a typical encounter includes primarily the components shown on Figure 4. Considering the magnitude and uncertainty of the components, kinematic lead is obviously the most important factor to be dealt with in a gunsight. The mathematical definition for kinematic lead is shown briefly in Figure 5. Although some simplifying steps are used here, the general relationship is:

$$\lambda = \frac{\dot{\Sigma} R}{V_m}$$

Where

λ = lead angle
$\dot{\Sigma}$ = line of sight rate
R = range
V_m = muzzle velocity (average)

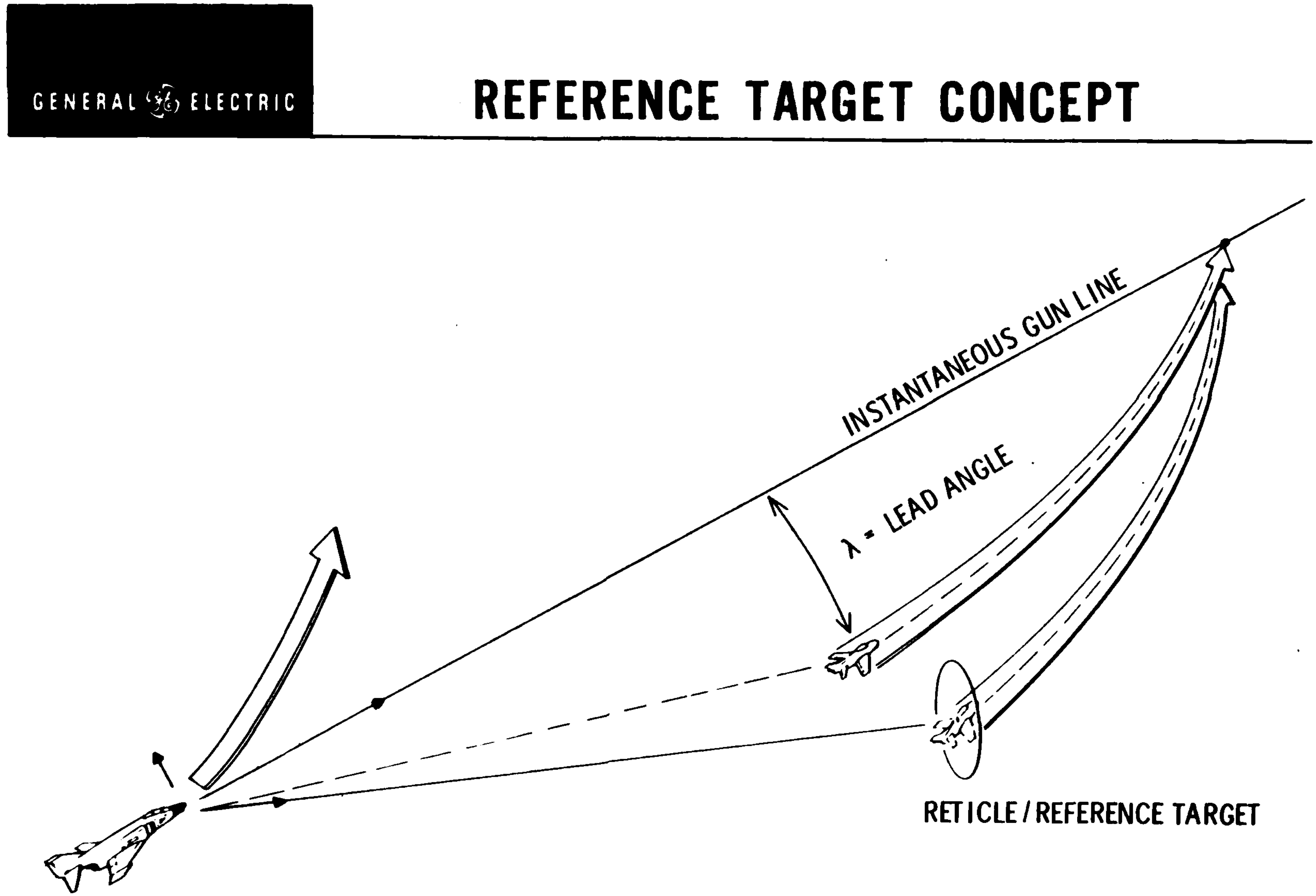

GENERAL ELECTRIC
REFERENCE TARGET CONCEPT
INSTANTANEOUS GUN LINE
λ = LEAD ANGLE
RETICLE / REFERENCE TARGET

Figure 2.

GENERAL ELECTRIC

REFERENCE TARGET CONCEPT

PILOTS VIEW

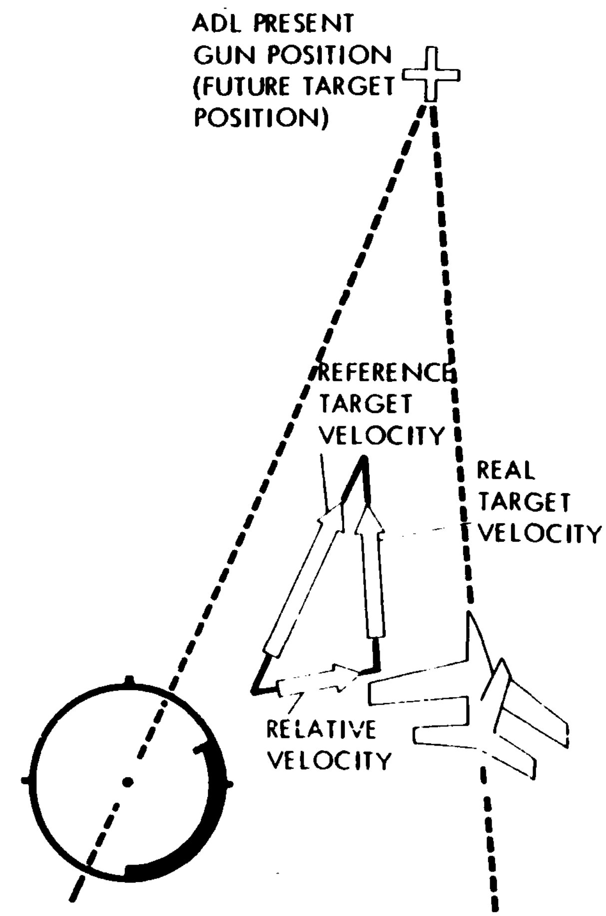


Figure 3.

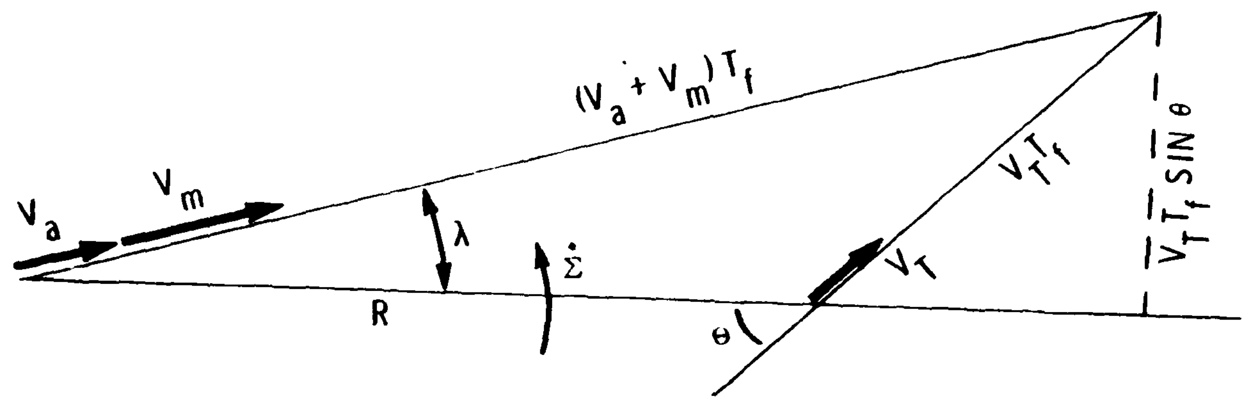
GENERAL ELECTRIC

COMPONENTS OF LEAD ANGLE

	MAGNITUDE	UNCERTAINTY
• KINEMATIC LEAD	180 MILS	
- TARGET VELOCITY	155 MILS	10 MILS
- TARGET ACCELERATION	25 MILS	7 MILS
• GRAVITY DROP	5 MILS	0.5 MILS
• TRAJECTORY SHIFT	12 MILS	2 MILS
• OTHER		1 MIL
ROUND-TO-ROUND DISPERSION		2.5 MILS
TARGET SIZE		10 MILS x 10 MILS

GENERAL ELECTRIC

KINEMATIC LEAD



$$\lambda \cong \text{SIN}\,\lambda = \frac{V_T T_f \text{ SIN } \theta}{(V_a + V_m)T_f} = \frac{V_T \text{ SIN } \theta}{V_a + V_m} \qquad (1)$$

$$\dot{\Sigma} = \frac{V_T \text{ SIN } \theta}{R} - \frac{V_a \text{ SIN } \lambda}{R}$$

$$\dot{\Sigma} R \cong V_T \text{ SIN } \theta - V_a \lambda \qquad (2)$$

FROM EQ. (1) AND (2)

$$V_T \text{ SIN } \theta = \lambda(V_a + V_m) = \dot{\Sigma} R + V_a \lambda \qquad \lambda V_m = \dot{\Sigma} R$$

$$\lambda = \frac{\dot{\Sigma} R}{V_m}$$

Figure 5.

Although a variety of gunsight mechanizations exist, they all must in some way deal with this basic relationship. A director system for example is a straightforward solution where Σ and R are measured, and knowing V_m, the lead angle λ is computed. Although this seems to be the obvious way to build a gunsight, results have been poor because the measurement of Σ has been difficult with available sensors; i.e., the radar. Future success is hoped for with E/O trackers where the noise characteristics of the measured rates are expected to be better than for a tracking radar.

Tracer and LCOS mechanizations eliminate the problem of tracker noise on observed line-of-sight rate by measuring the other parameters of the equation and effectively displaying line of sight rate in the reticle movement. However, this process causes an interaction between reticle dynamics and aircraft control dynamics which will be discussed later.

Shifting to another aspect of the gunnery probiem, consider the potential envelope of the gun independent of the lead angle calculations. Figure 6 gives an indication of the range limits from different positions relative to the targets heading. One indication of maximum range in the aft sector is a function of fuzing capabilities of the bullets. In the "six o'clock" position relative range is limited to under 3,000 feet. The reason for this is seen in Figure 7 where at 500 kts. true airspeed, bullets reach a relative range rate (and thus an impact velocity) of zero at a range just over 3,000 feet. As the angle off the tail of the target increases, the fuzing range limit opens to much greater ranges. The practical limit then becomes time-of-flight.

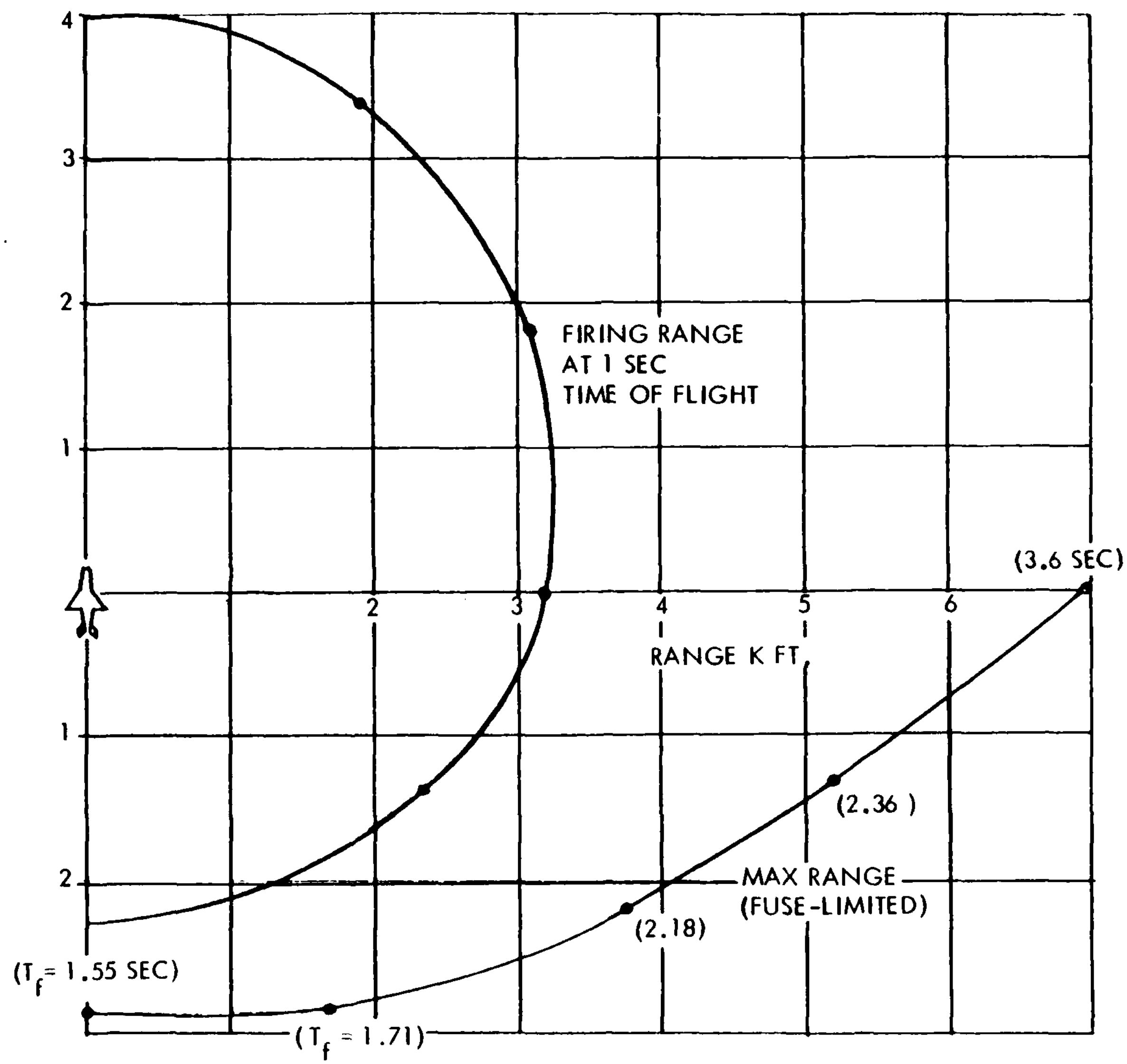
The range limits due to bullet time of flight result primarily from target accelerations in evasive maneuvers. Once the bullet is fired, it is obviously impossible to correct the aim based on subsequent target maneuvers. In a one second time-of-flight situation for a target at 3,000 feet, an acceleration change of 2 g's across the line-of-sight will generate a bullet error of about 10 mils, or close to one target diameter. As time of flight increases beyond one second, significant errors build up because of the uncertainty of target motion.

The point then is that at one second time-of-flight, effective gunnery is possible. In terms of range, this means gunnery is possible out to 4,000 feet for front quarter shots. The combat capability is then limited by control and display techniques and over-nose vision limits, but not gun performance. Improved 20 mm rounds are currently under development which will even increase this potential envelope.

GENERAL ELECTRIC

GUN ENVELOPE

TAS= 500 KTS
TARGET= 500 KTS
6000 FT. ALTITUDE



GENERAL ELECTRIC

M-56 BALLISTICS

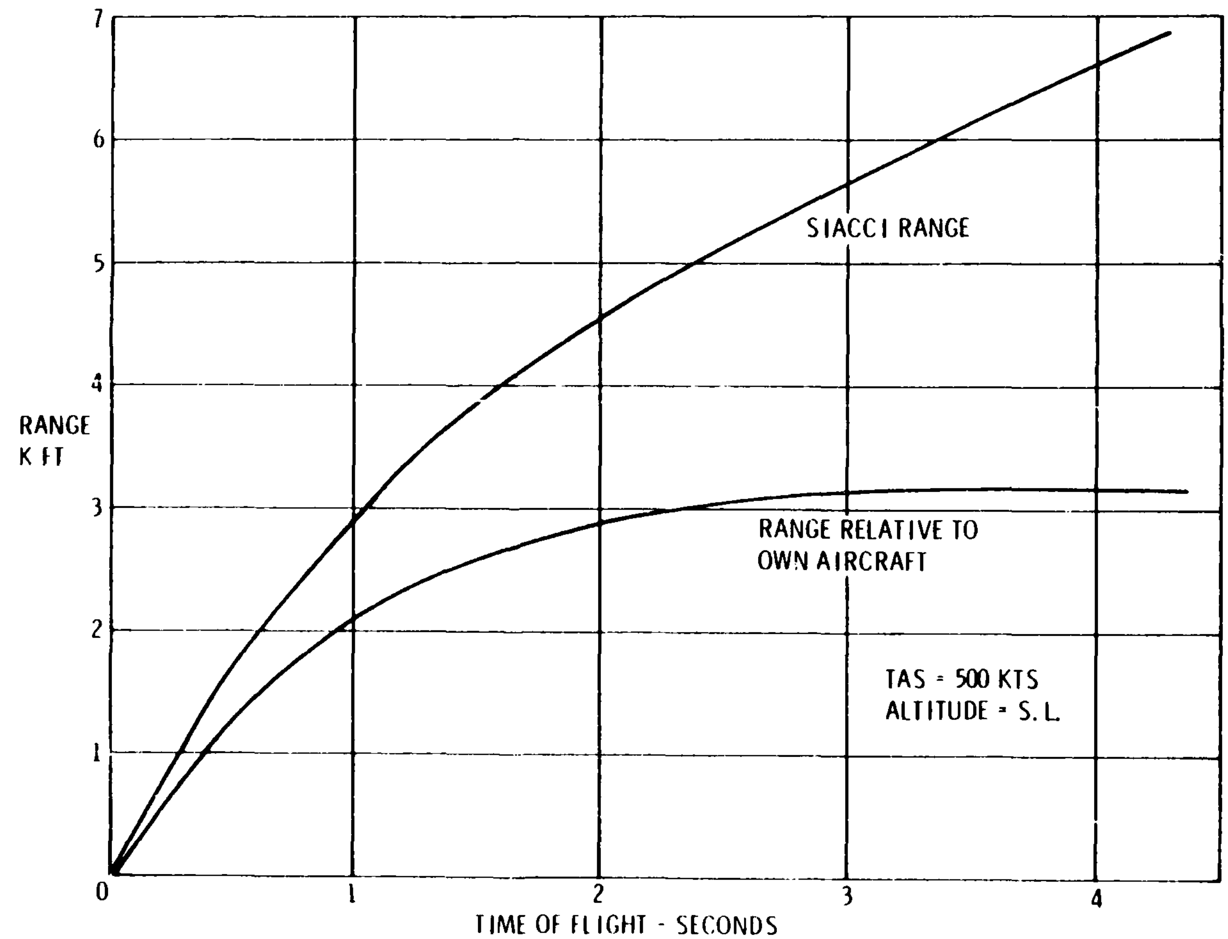


Figure 7.

GUNSIGHT MECHANIZATIONS

The primary gunsights in use or in development today make up a relatively short list.

- Fixed reticles
- Lead Computing Optical Sights (LCOS)
- Tracer Sights
- Director Sights
- Multiple Reference Gunnery System (MRGS)

Although each of these deal with the same lead angle problem, they each emphasize different functional requirements. In terms of the reference target concept, they are each appropriate gunnery references for different encounter situations. The fixed reticle can be used in aerial combat for very short ranges. The gun boresight cross is perhaps the best reference when the target fills the windscreen at less than 500 feet. Since this situation is limited to relatively few encounters, more sophisticated systems are required for longer range situations. In terms of range, the tracer is useful in the 500 to 1000 ft. situations, particularly where tight rolling maneuvers are encountered. Beyond 1,000 feet, a LCOS or director sight is more appropriate because of its stability in terms of control dynamics. The MRGS, which deals specifically with high deflection situations, extends the range possibilities out to 4,000 feet. Although any of these gunsight concepts can be used over the entire encounter spectrum, they provide high kill probabilities only in the sectors where they are good reference targets for the situation at hand. Pilot skill is required to adapt the gunsight capabilities of his aircraft to all the situations he faces. In the future, a blend of all these gunsights will hopefully give him gunsight symbology to handle a wide range of situations. Hopefully this will be possible without a cluttered CRT HUD symbology format.

Symbology for current gunsights are shown in Figure 8; and. at first glance, they don't appear to suggest a great difference in algorithms or mechanizations. The LCOS and Digital LCOS (DLCOS) use the circular reticle with range analog bar typical of electromechanical sights. The tracer sight displays electronic bullets with stadiametric range marks and a diamond at target range when radar lock-on is present. Although derived from bullet data rather than target parameters, the tracer diamond is a " reference target for which the gun is correctly aimed". Its control dynamics differ considerably from LCOS because of the transport lag (one time-of-flight) between control stick inputs and the "inertial" position of displayed bullets. The director sight employs a reticle and possibly a box showing authority limits of a flight control in the case where automatic control is used. Symbology for the Multiple Reference Gunnery System is of similar complexity, although very different in mechanization.

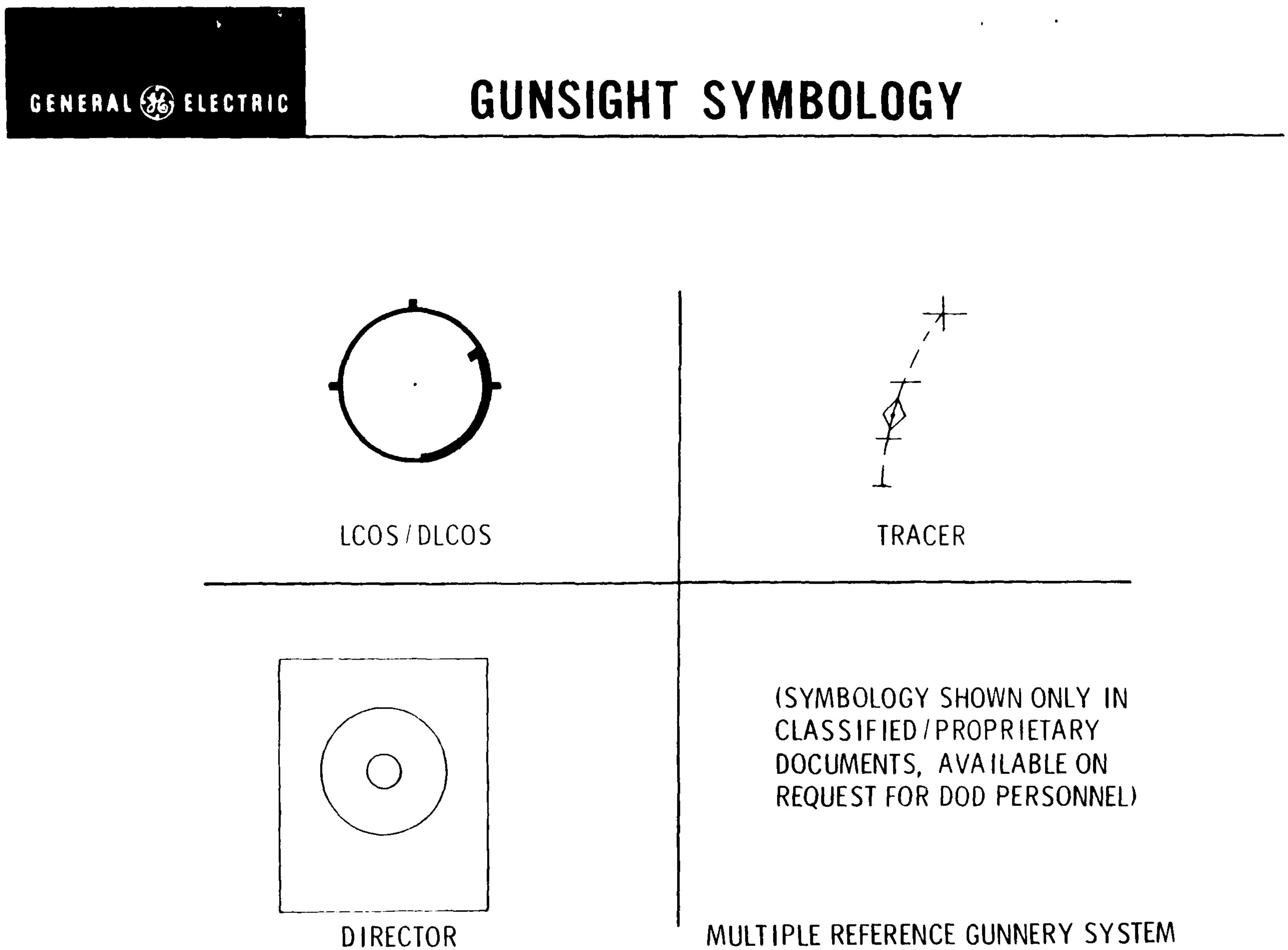

GENERAL ELECTRIC
GUNSIGHT SYMBOLOGY
LCOS / DLCOS
TRACER
DIRECTOR
(SYMBOLOGY SHOWN ONLY IN CLASSIFIED / PROPRIETARY DOCUMENTS, AVAILABLE ON REQUEST FOR DOD PERSONNEL)
MULTIPLE REFERENCE GUNNERY SYSTEM

Figure 8.

An additional form of comparison is related to the hardware used for each mechanization. Figure 9 shows the principal hardware elements excluding air data parameters and mode select functions. The traditional LCOS systems employ electromechanical elements. Both a tracer and a digital version of the LCOS function can be provided using a digital computer, three axis rate information and range. For director sights, the measurement of line-of-sight rate requires an electro-optical tracker although attempts are still being made to get useful performance with tracking radars. Hardware for the MRGS is similar but requires no radar range for high deflection opportunities.

CONTROL DYNAMICS

The useability or controllability of a gunsight reticle results from a compiex interaction between the pilot, the airframe, the flight control, and the gunsight equations. Figure 10 depicts the total control loop which shows that the error signal is perceived by the pilot visually through the HUD. From that point, loop closure and its attendent stability depends on the characteristics of the three transfer functions in series. Analysis of this control problem has been the subject of many studies. The following excerpts from "Control and Display Factors in Air-to-Air Gunnery", (GE ACS 10, 294), by R. P. Quinlivan and G. Tye, show the complexity of the subject and the variations in the longitudinal axis.

> The relationship between the gun line and the elevator or stabilator in the longitudinal axis of a typical fighter may be expressed in transfer function form as:
>
> $$\frac{\theta}{\delta_s} = \frac{\left(K\,\omega_{sp}^{\;2}T_q\right)\left(S + 1/T_q\right)}{S\,[S^2 + 2\,\xi_{sp}\,\omega_{sp}\,S + \omega^2_{sp}]} \tag{4}$$
>
> This must be coupled to the dynamics of the aiming reference.
>
> In the case of the director system, the sight is driven independently of aircraft motion. Therefore, the transfer function from the stabilator to the aiming reference is approximately the same as (4).
>
> For the LCOS sight, the aiming reference is dependent on the motion of the aircraft.
>
> $$\dot{\lambda} + \lambda/T_f = q + \frac{a_n}{2V_f} \tag{5}$$

GENERAL ELECTRIC

GUNSIGHT HARDWARE CONFIGURATIONS

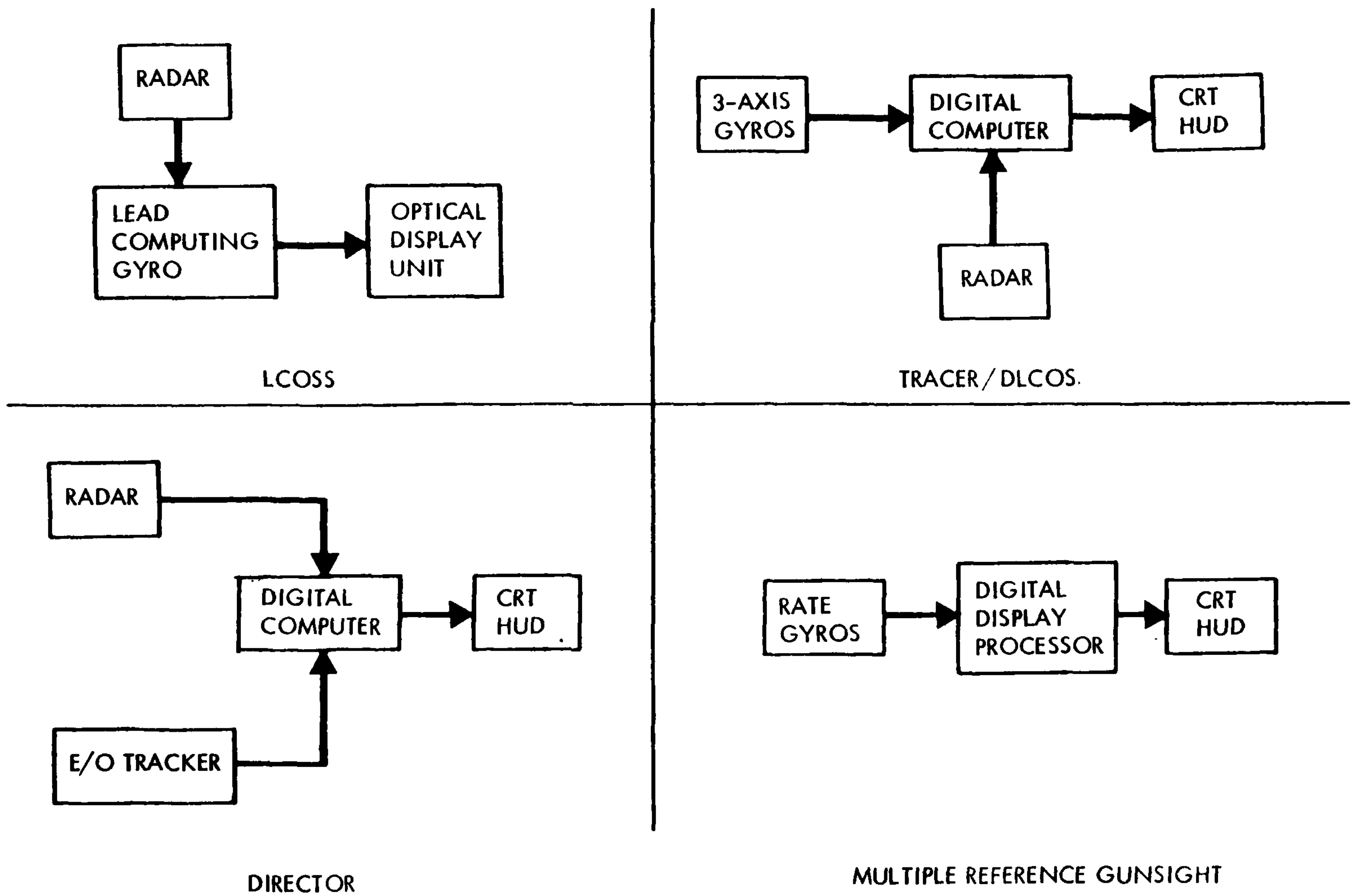


Figure 9.

GENERAL ELECTRIC

GUNSIGHT CONTROL LOOP

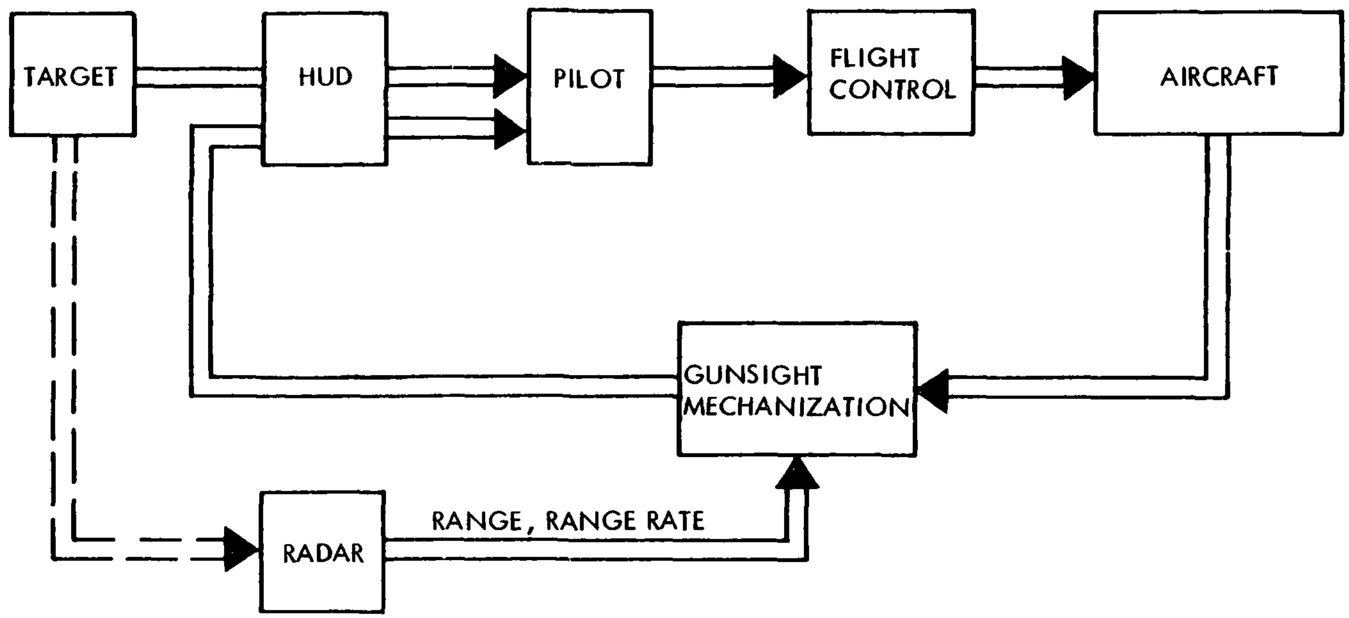


Figure 10.

Since

$$\Sigma_q = \theta - \lambda, \tag{6}$$

a combination of (4), (5) and (6) leads to:

$$\frac{\Sigma_q}{\delta_S} = \frac{K}{S(1 + 2\xi_{sp}/\omega_{sp} S + S^2/\omega_{sp}^{\;2})} \times \frac{1 + S\left(T_q - \frac{T_f}{2V_f} U_o\right)}{1 + ST_f} \tag{7}$$

In a tracer sight, the portion of the tracer line at target range obeys the following equation:

$$\lambda = \theta(1 - e^{-sT_f}) + \frac{a_n}{2V_f} T_f \tag{8}$$

For the first order Padé approximation for e^{-sT_f},

$$\lambda \approx \theta\left[\frac{ST_f}{1 + ST_{f/2}}\right] + \frac{a_n T_f}{2V_f} \tag{9}$$

Combining (4), (6) and (9),

$$\frac{\Sigma_q}{\delta_s} = \frac{\left[K \quad 1 + S\left(T_q - \frac{T_f}{2} - \frac{U_o}{2V_f} T_f\right) - S^2\left(T_q T_f + \frac{U_o T_f^{\,2}}{4V_f}\right)\right]}{S\left[1 + \frac{2\xi_{sp}}{\omega_{sp}} S + \frac{S^2}{\omega_{sp}^{\;2}}\right] \left[1 + ST_f\right]} \tag{10}$$

In order to compare the tracking dynamics for the three sighting means, it is convenient to use some typical numbers for the variables in (4), (7) and (10).

$T_q = 1.0$

$T_f = 1.0$

$\omega_{sp} = 3.5$

$\xi_{sp} = 0.25$

$V_A = 800$ fps

$V_f = 2700$ fps

- Director $\dfrac{\Sigma q}{\delta_s} = \dfrac{K[1 + S/1]}{S[1 + 0.157S + 0.09S^2]}$ (11)

- Disturbed $\dfrac{\Sigma q}{\delta_s} = \dfrac{K[1 + S/1]}{S[1 + 0.157S + 0.09S^2][1 + S/1]}$ (12)

- Tracer $\dfrac{\Sigma q}{\delta_s} = \dfrac{K[1 + S/1.87][1 - S/2.91]}{S[1 + 0.157S + 0.09S^2][1 + S/2]}$ (13)

Inspection of the equations allows certain observations to be made.

Manual control theory shows us that the man in the control loop will attempt to equalize the plant plus man frequency characteristics so as to have a system at crossover which can be represented as:

$$Y_p Y_m = \frac{\omega_{co}}{S} e^{-\tau S} \tag{14}$$

It is therefore proper to examine manual control systems relative to (14) with the objective of not requiring the pilot to insert appreciable compensation dynamics. This is especially important in problems such as this which are multiloop and multiaxis.

One common problem with all three systems described by (11), (12) and (13) is the quadratic in the denominator which is underdamped to the point where artificial damping is required. Since the numbers used in computing (11), (12), and (13) are only representative, both the frequency and damping are functions of flight condition and, therefore, will vary considerably.

A further indication of the control problem comes from examination of the lateral axis, Figure 11. Control of the lateral gun aim is fundamentally less stable than the pitch axis because of the cross coupling of pitch rate and the additional integration within the control loop. These problems are frequently demonstrated in gun camera film by a reticle which oscillates laterally across the target. Current flight control techniques are capable of solving these control problems when a complete system approach is applied to the combined flight control and fire control design.

GENERAL ELECTRIC

CONTROL OF LATERAL GUN AIM

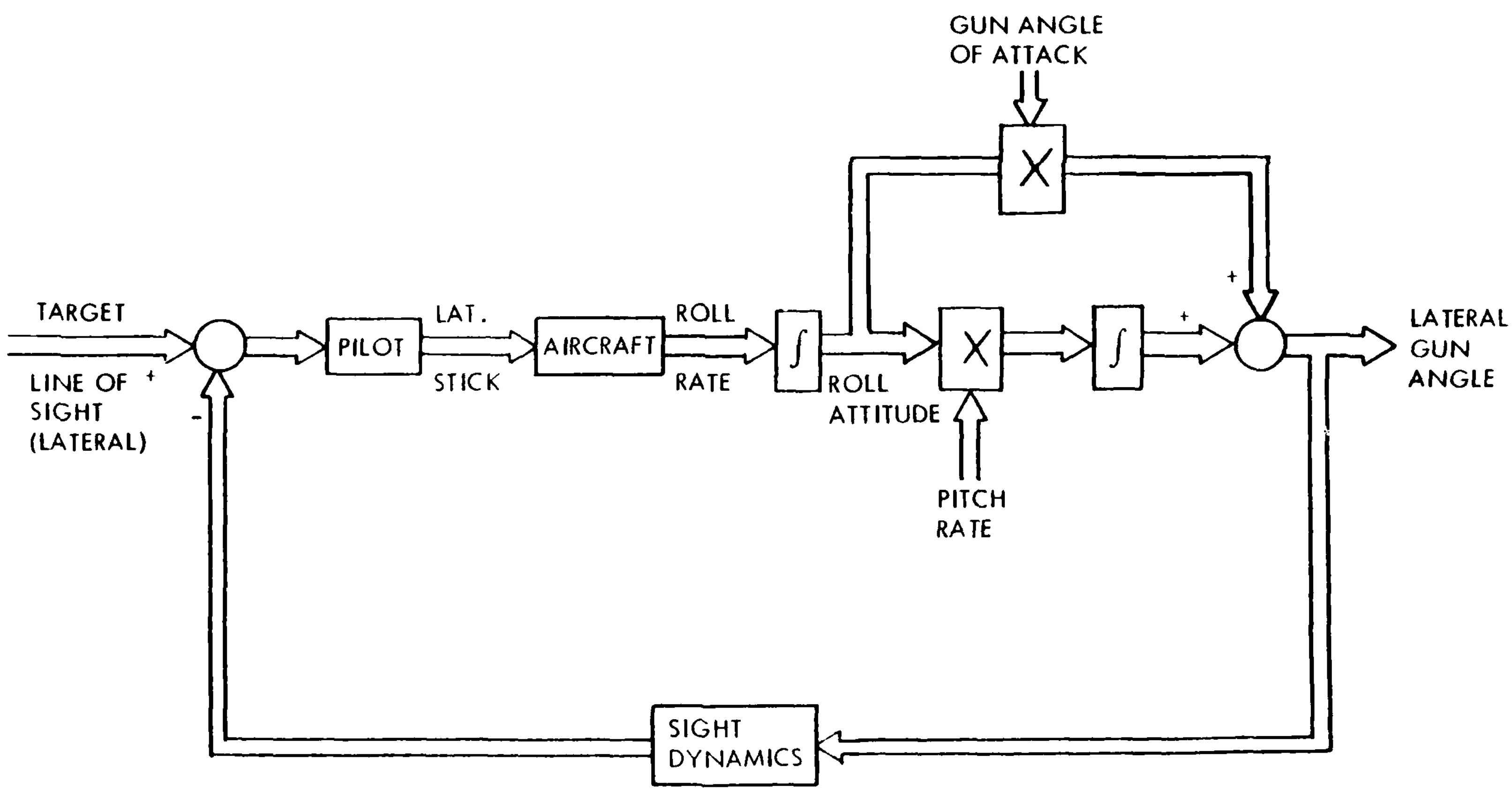


Figure 11.

1) Display techniques for aerial gunnery requires careful integration of the entire avionics network:

- Fire Control Processor
- Flight Control System
- Air Data Computer
- Rate Sensors
- Acceleration Sensors
- CRT HUD and Symbol Generator
- Radar System
- Gun and Ammunition Handling System
- E/O Tracker
- Stores Management System

2) Continued evolution of aerial gunnery techniques, including hardware and software performance, will expand the capability of the gun in the role of air superiority. The driving force in this evolution will come in the form of:

- Improved ballistics
- Increased HUD field of view
- Flexible gun techniques
- Improved E/O trackers
- Flexibility in display symbology
- Aircraft CCV techniques
- New missile capabilities
- New concepts for gunnery algorithms

3) Analysis, simulation, and flight test programs are required to develop and validate new techniques.

4) The capability of the Multiple Reference Gunnery System to provide effective high deflection gunnery performance is an example of how technological growth has created new and better solutions to long standing problems. (Contact the author for additional details on MRGS.)

RADM MANDEVILLE

REMARKS FOR LUNCHEON ADDRESS 20 MAY 1976

THIRD ADVANCED AIRCREW DISPLAY SYMPOSIUM

AUDIENCE: Equal mixture of industry, military, civil service and some related agencies (FAA, NASA), a couple of Foreign Nationals.

THRUST: To keep things moving, i.e. get the players together, improve communication.

HOST: RADM Foxgrover

SPONSOR: VADM Lee

As you have already perceived, the luncheon speakers are out of order. RADM Seymour told you how NAVAIR was going to carry out OPNAVs requirements without knowing just what that requirement was.

In September of 1975, an OR (Operational Requirement) was signed by Admiral Armstrong which clearly stated the operational need for an aircrew display system that would provide for the design of cockpit displays as a visual information system capable of management by exception, sensor integration, reduced workload, modular construction for maintainability and flexibility. This OR (OR-WSL-65) is called Advanced Integrated Display Systems or AIDS.

In order to meet this requirement, the AIMIS program was begun in FY76, and now will be called AIDS. This program encompasses a study of operational requirements for the display system, some of which you have already heard. These requirements are assimilated and applied to the simulation work at the Naval Air Development Center. The best results from these will be put into a flight evaluation which is separate from any specific airframe commitment. These results are then translated into specifications for software and the known mission requirements.

What are the known mission requirements? The F18 can be assisted with this plan but only to the extent of validation. The VAMX is the next major weapon system and the one to benefit from the full AIMIS concept. The FPX and advanced VSTOL will follow.

An area of considerable interest to us at OPNAV is the training role to be played by such a system. At the present time, our front line VA and VP aircraft (A4 (ECP1120) A7 and F14) all have HUDs and electronic displays, and it is certainly likely all future air vehicles will have electronic displays. Yet, at the present time our advanced jet trainers and instrument trainers do not have electronic displays much less HUDs. If the benefits in all weather landing utilizing the HUD is to be fulfilled, then our training programs should have this capability also. The VTX therefore, must be a reflection of the fleet

capability. While this may seem obvious, there are still some bean counters that don't understand pilot training effectiveness. Perhaps that is the challenge to all of you, prove the effectiveness of the concept.

There are other requirements coming as sensor capability is improved, as IFF becomes more critical to our non-visual weapons (because without an effective IFF, of what value is the non-visual weapon) and the proliferation of subsystems like JTIDS, ULAIDS and TACSTRAT all of which assume to utilize the display face of AIDS. AIDS has become much more than the "sacred six" with which we pilot an airplane. It is the command and control I-O device. Not much can be more important than that, unless it is the engine in a single engine airplane.

From what I have said so far, you can see just how important the response to the AIDS operational requirement is. I know that the funding is tight but we in OPNAV will see to it that you are supported according to your success. The potential for a "tactical edge" is here. I am told that the technology is ready, we must now execute the program to our capability.

EVALUATING THE CHARACTERISTICS OF LUMINOUS COLORED COCKPIT DISPLAYS

J. BURNS

DuMont Electron Tubes and Devices Corp.—Clifton—N.J.

EVALUATING THE CHARACTERISTICS OF LUMINOUS COLORED COCKPIT DISPLAYS

J. BURNS

DuMont Electron Tubes and Devices Corp. - Clifton - N.J.

I - INTRODUCTION

In flight, an aircraft pilot needs a constant knowledge of certain data, which he can only obtain visually. Recently, data presentation systems have been evolving towards electronic readout on display screens. This type of display satisfies two needs which have been created by the evolution in navigation conditions :

1) The amount of information the pilot must acquire visually is constantly increasing, even with conventional piloting techniques. At the moment, the data is acquired sequentially by eye, and is subsequently synthesized in the pilot's brain.

   The capacity and safety of this method of data presentation are limited :

   a) By the recognition, recording, and synthesizing capabilities of the pilot,

   b) By the predetermined route the eye follows in acquiring data ; this is already onerous in terminal flight zones and cannot exceed a certain saturation level without risk of error.

   Consequently, the present tendency towards the simultaneous display of preselected data on "Multifunction" penetration screens reduces both data acquisition time and risks of errors.

2) New navigation and approach techniques, using onboard computers, virtually necessitate the display of the computed information in an integrated analog form on a screen. For this, the cathode-ray tube (CRT) has incomparable advantages over other display systems in its capability of displaying a high density of information in color.

   Other systems that look promising, although still in the development stage, are :

   - Liquid crystal panels,
   - Gas discharge panels,
   - LED or EL mosaïc displays.

The Use of Color in Luminous Data Displays

When using a monochrome display screen, all of the information appears in the same color (the background luminance of the screen possibly being of a different color), so separate data can only be distinguished by shape and brightness.

When using a multichrome screen, each parameter can be displayed in a different color, according to a predetermined code, and the background can be of yet another color. This yields a number of uncontested advantages, as compared with monochrome displays :

- Increase in displayable information density,
- Greatly reduced data acquisition time,
- Greatly reduced risk of error in symbol and number identification,
- Possibility of color-coding, yielding supplementary information without requiring a shape-coding system.

At present, two types of color displays are commercially available :

- Color penetration CRT's,
- Electromechanical head-up display's.

Luminous Environment of the Instrument-Panel Display

The total ambient lighting under which a display is observed can be considered in two parts :

1) The light falling directly onto the screen. This can vary between three distinct levels :

   a) Zero or low-level lighting (below 0.1 lux),

   b) Typical lighting (1000 lux), corresponding to the mean intrument panel illuminance during a daytime flight with a clear sky, well above a layer of clouds,

   c) Extreme lighting (70 000 lux), corresponding to direct sunlight falling nearly perpendicularly onto the screen.

2) The luminous environment, this being the luminance of the surfaces surrounding the pilot, to which his eyes have become adapted. This modifies readability, not by affecting the intrinsic characteristics of the display, but by altering the properties of the eye.

Aims of the Study

The work presented here was aimed at determining a means of evaluating the intrinsic properties of a display system. The procedure involves introducing the idea of "Detection and Identification Index" for colored signals displayed on a screen subject to any ambient lighting conditions, and the measurement and calculation of this index for each information display under the operating conditions encountered.

The minimum values of the above index, corresponding to rapid, comfortable, and error-free acquisition of information by detection and identification of luminous signals, have been determined experimentally.

II - THE BASIS OF THE APPROACH : LUMINANCE DIFFERENCE, COLOR DIFFERENCE, AND THEIR EQUIVALENCE

The work carried out was based on both theory and experimental results :

Taking into account the work of Judd and MacAdam on the visual perception of color differences, a photocolorimetric space is defined, which relates to luminous sources as opposed to colored reflecting surfaces. In this space, an identical distance between two points representing two different luminous sources always represents an identical difference in visual impression.

The equivalences between color and luminance, as well as the determination of detection limits, are deduced from physiological color detection tests carried out under all types of piloting conditions, i. e. :

- With screen illuminance varying from 0.1 lux to 70 000 lux,
- Under variable luminous environment, including dazzling by an external luminous source.

The color display system used was a color penetration CRT developed by THOMSON-CSF for a head-down display system.

Definition of a "Detection and Discrimination Index" Relating to Visual Perception

It was decided to establish an equivalence between the perception of a difference in luminance, and the perception of a difference in color. To do that, the concepts of luminance difference, unitary luminance difference and luminance discrimination index must be introduced.

> Note : Throughout the following discussion, the letter symbols used (EL, Es, IDL, etc.) correspond to the French names of the quantities involved, because of the pioneering work of our parent company, THOMSON-CSF, in this field.

Two luminous signals (or a signal on a luminous background) of luminance L_1 and L_2 have a contrast ratio,

$CR = \frac{L_1}{L_2}$, where $L_1 > L_2$. The visual perception of luminance being a logarithmic function of stimulus, thus of source luminance, the term "Luminance Difference" is defined as being the logarithm of contrast ratio :

$$\text{Luminance Difference, } EL = \log CR.$$

Perception Threshold, Es

It is generally accepted that for maximum eye sensitivity, the minimum contrast ratio that can be discerned is 1.05, this corresponding to 5 % relative variation in luminance. By definition, the Luminance Difference Threshold (or Perception Threshold) Es, is the smallest difference in luminance that a standard observer can detect :

$$Es = \log 1.05 = 0.021$$

Unitary, or Reference Luminance Difference, ELU

The preceding concept introduces the idea of a discernability threshold, and it is also natural to introduce an idea of comfort. It is accepted that a contrast ratio $CR = \sqrt{2}$ is required for comfortable discrimination between two pieces of monochrome information (this is the definition of the half tone in photography and television). Under these circumstances, the Luminance Difference is defined as being the Unitary Luminance Difference (ELU) and is given by :

$$ELU = \log\sqrt{2} = 0.15.$$

Note that ELU is 7 times Es.

Luminance Discrimination (or Detection) Index, IDL

This is defined as being the Luminance Difference EL divided by the Unitary Luminance Difference ELU.

$$IDL = \frac{EL}{ELU} = \frac{\log CR}{0.15}$$

It is also necessary to establish similar definitions for chrominance, by starting from the idea of differences in color. We have done this by using the CIE 1960 (U, V) chromaticity diagram. In that diagram, all existing colors are represented by two coordinates (U and V). So long as the distance between two color points is the same, the impression of color difference is identical no matter where the actual points lie within the color triangle (i. e. no matter what their color may be).

Chrominance Difference, EC

This is defined as the distance between the two points (U, V) :

$$EC = (\Delta U^2 + \Delta V^2)^{1/2}$$

Chrominance Threshold, Es

This is defined as the smallest discernable color difference, and has been determined to equal 0.00384, i. e.,

$$Es = 0.00384 \quad (U, V).$$

Unitary Chrominance Difference, ECU

Several possible definitions could be envisaged :

1) Chrominance difference equal to 7 chrominance thresholds (analogous to luminance).

2) Chrominance difference for comfortable discrimination between two colors.

3) Chrominance difference giving the same impression of contrast as a unitary luminance difference.

Physiological laboratory tests showed that these three definitions were equivalent, so we define :

$$\boxed{ECU = 7\ Es = 0.027}$$

Chrominance Discrimination Index, IDC

This is defined as being the Chrominance Difference, EC, divided by the Unitary Chrominance Difference, ECU.

$$IDC = \frac{EC}{ECU} = \frac{EC}{0.027}$$

Detection Index and Discrimination Index

In cases where contrast is due to both color and luminance differences, the combined index ID is defined as being :

$$ID = (IDL^2 + IDC^2)^{1/2}$$

ID is known as "Detection Index" when detecting luminous signals of the same color on a background of a different color, and "Discrimination Index" when differentiating between two signals of different color and luminance.

In colorimetric terms, this is equivalent to representing a luminous source of color C (U, V) and of luminance L by a point of carefully chosen coordinates in a three dimensional space (U, V, log L). The Discrimination Index between two such sources is represented by the distance between the corresponding points. Kowalisky has submitted a space of this type to the CIE for acceptance as a standard (see figure ¹).

Measurement of Detection Index

Consider a luminous signal having characteristics (U_s, V_s, L_s) as measured on a dark screen (which may or may not have a contrast filter) that receives incident illumination.

The screen, after reflection of the incident light, will appear to be a luminous source having measured or calculated parameters (U_e, V_e, L_e). The photocolorimetric characteristics of the signal will thus be modified ; the two luminances combine to give $L_s + L_e$, and the color point will to $U_s{}'$, $V_s{}'$ (generally by desaturation of the colors).

$$IDL = \frac{1}{0.15} \cdot \log \frac{L_s + L_e}{L_e}$$

$$IDC = \frac{1}{0.027} \cdot \left[(U_s{}' - U_e)^2 + (V_s{}' - V_e)^2 \right]^{1/2}$$

$$ID = (IDL^2 + IDC^2)^{1/2}$$

We have thus established a means of specifying the characteristics of a system displaying colored luminous information on a screen subject to any type of incident lighting. It is now only necessary to define the minimum value of the Detection Index that corresponds to a usable display (rapid, comfortable, and error-free acquisition of the information).

RESULTS OF PHYSIOLOGICAL TESTS : EFFECTIVE DETECTION INDEX - NUMBER OF COLORS

Number of Colors Usable in a Color Display System

Each color must be separately identifiable, and not simply distinguishable in the presence of other colors. According to various authors, the possible number of identifiable colors varies from 5 to 15. We believe that no more than 4 should be used : the risk of identification error increases with the number of colors when they become desaturated under intense incident illumination.

After extensive testing, we have selected three out of the four colors, defined by their equivalent wavelengths :

Red : $\lambda \geq 612$ nm

Amber : $\lambda = 580$ nm

Green : $500 \text{ nm} \leq \lambda \leq 555$ nm.

In theory, the Identification and Discrimination Index for these three colors should be equal to 1. To verify that, we carried out several physiological experiments, including complete simulation of the normal aircraft-cockpit luminous environment.

Ambient-Lighting Simulator

An ambient-lighting simulator was constructed, enabling tests to be carried out with many different observers. Before doing this, however, a series of photometric measurements were taken to determine instrument panel illuminance and the luminous environment found in the cockpit of an aircraft in flight. These measurements were taken in a Boeing 707 for all possible conditions : various altitudes, clouds, blue sky, direct sunlight, at midday and at sunset, and so forth.

The dimensions of the simulator are similar to those of the Boeing 707 cockpit. Facing the pilot is a color graphics and alphanumeric display. A series of independently variable light sources enable any of the previously measured luminous environments to be reproduced :

- Screen and instrument panel illumination up to 70 000 lux ;
- Variable ambient luminance inside the simulator ;
- Variable luminous environment outside the windshield, to simulate the sky and clouds.

The display system is a color penetration CRT whose color and luminance are continuously variable.

Test specification

Different operators adjust the luminance of the display so as to obtain error-free detection and identification of the symbols under various ambient lighting conditions. Ideas of detection threshold and comfortable detection are introduced. The Detection Index is then measured in the manner explained above.

Weighting the Detection Index

It turns out that the Detection Index must be weighted to take account of two physiological factors :

1) Sensitivity of the eye to contrast as a function of screen luminance (standardized by the CIE)

   A pilot notices that his eyes' sensitivity to contrast is diminished when observing a screen having a background luminance below 10 000 cd/m^2.

   The Relative Contrast Sensitivity coefficient, RCS, is given in figure 2.

2) Transient Adaptation Factor

   A second factor which must be taken into account is the temporary loss in sensitivity of the eye which occurs when the pilot, initially looking elsewhere (eye adapted to the internal or external luminous environment), looks down at the screen.

   A Transient Adaptation Factor, TAF, has been defined by the CIE ; it takes into account the temporary change in eye characteristics as a function of the ratio of the ambient luminance and the screen luminance (see figure 3).

   When a pilot looks at the display, his eye is not adapted to that luminance level and, during the adaptation time, its sensitivity is decreased. Contrary to the RCS, which is independent of time and depends only on the background luminance of the screen, the TAF depends on time and on the ratio of the luminance of the adaptation zone to the background luminance of the screen.

   An Effective Detection Index (IDE) is defined to be independent of luminous environment conditions (see figure 4) :

$$\boxed{\text{IDE} = \text{ID} \times \text{RCS} \times \text{TAF}}$$

Experimental Results

Extensive experimentation has yielded the conclusion that no matter what the lighting conditions are, the Effective Detection Index values are as follows :

- At the detection threshold : $\boxed{\text{IDE} = 0.3}$
- For comfortable, error-free detection : $\boxed{\text{IDE} = 0.6}$

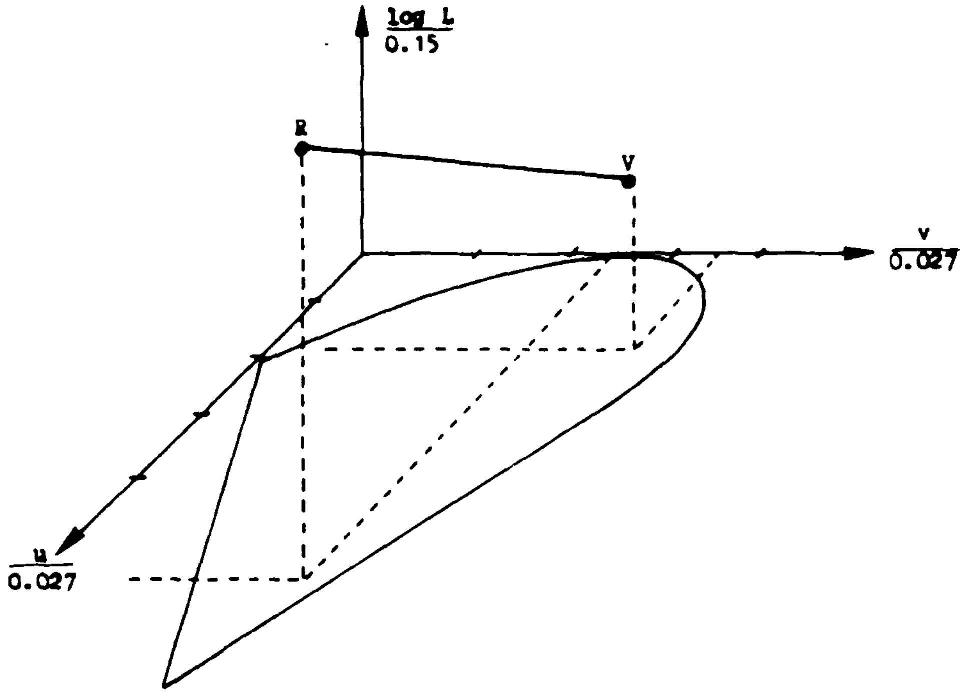


Fig. 1 - PHOTOCOLORIMETRIC SPACE (u, v, log L)

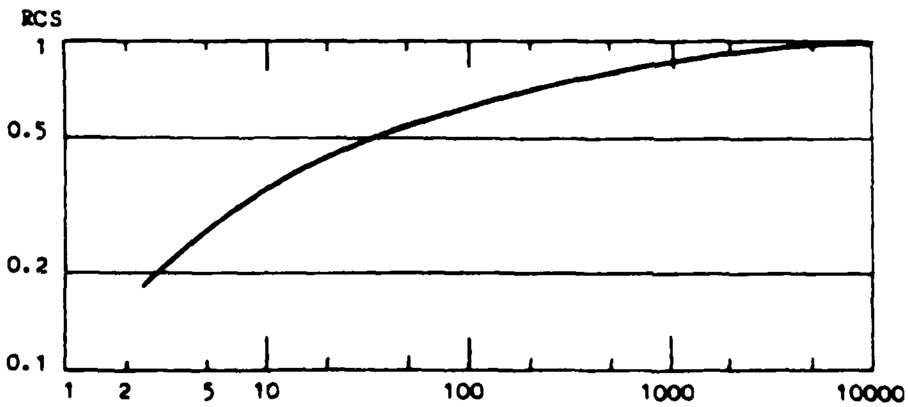


Fig. 2 - RELATIVE CONTRAST SENSITIVITY COEFFICIENT (RCS)
Versus background luminance

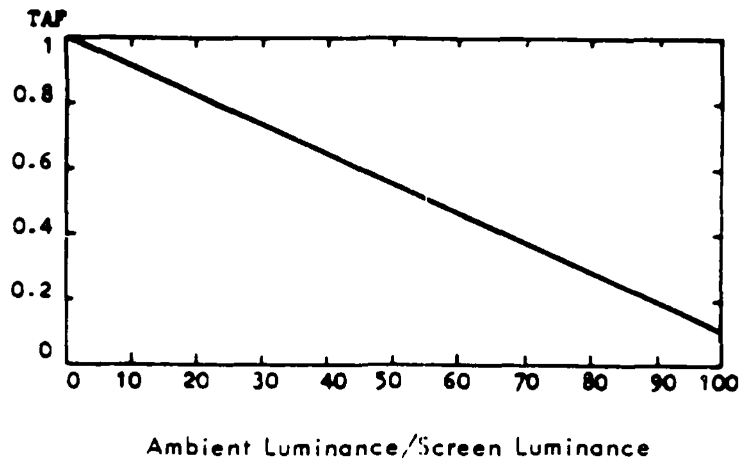


Fig. 3 - TRANSIENT ADAPTATION FACTOR (TAF)
Versus luminance ratio

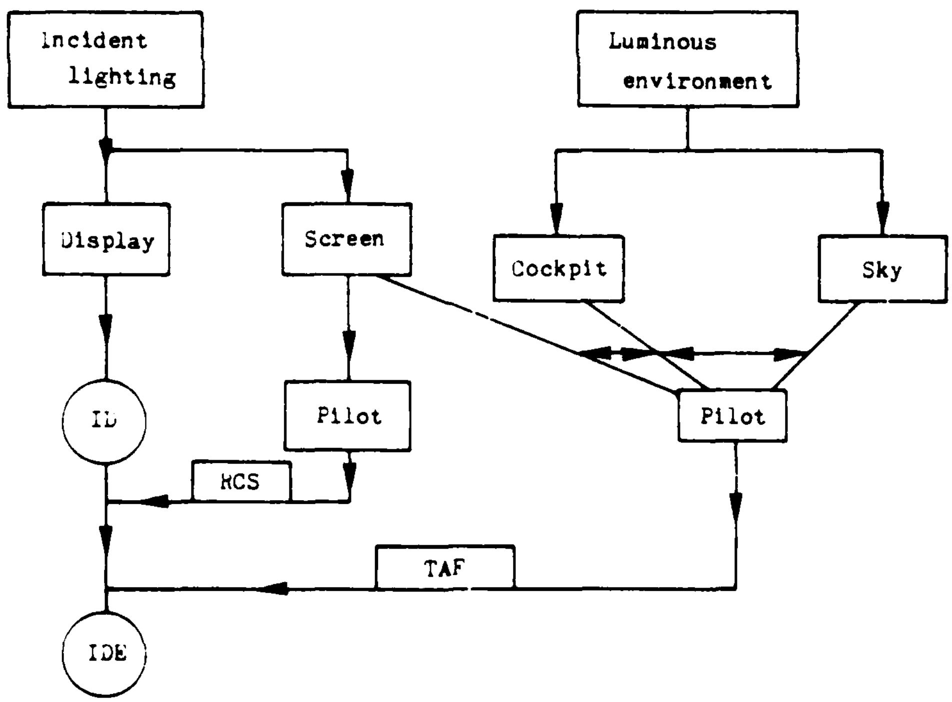


Fig. 4 - EFFECT OF ENVIRONMENT ON THE EFFECTIVE DETECTION INDEX.

Display systems can thus be classed into three groups by calculation of the IDE :

1. For IDE < 0.3 : detection is impossible, and the system should be rejected.

2. For 0.3 ≤ IDE < 0.6 : detection is not comfortable, and identification errors can occur in some cases.

3. For IDE ≥ 0.6 : the system permits comfortable detection and identification, and can be used under any ambient lighting.

CONCLUSIONS

A theoretical and experimental investigation has been carried out, partly based on CIE recommendations. It has enabled defining a Detection Index that allows easy and rapid evaluation of the efficacity of screen display systems under the luminous environments found on board aircraft in flight.

ABSTRACT

a. The need for warning and alerting devices in aircraft.

b. The significance of color to warning devices.

c. Lockheed/Loral development of a tactical color display.

d. Investigation of color enhancement in tactical displays.

e. Color display format investigation request.

f. An example of tactical situation where color is utilized as a warning device to a distracted operator.

g. Summary

INTEGRATED COLOR DISPLAY SYSTEM

By

L. D. Evans

Lockheed-California Company
Burbank, California

and

S. Storper

Loral Electronic Systems
Yonkers, New York

Lockheed appreciates the opportunity to participate in this Display Symposium and, as a Contractor that relies on displays as a communications media in our ASW systems, fully endorses the purpose and objectives of this meeting.

INTRODUCTION

For a number of years, aircraft manufacturers have conducted numerous studies on devices which provide a means of alerting the aircrewmembers to possible hazardous conditions. Master Caution lights, eject lights, and fire warning lights are only a few examples of the many devices found in modern aircraft. If you are the pilot of an S-3A conducting MAD localization at 500 feet and you begin to lose power on the #1 engine, a warning is certainly appropriate and essential to the safety of the flight. The impact of the alerted system's degradation on flight safety, the proper location of the alerting device, and the color necessary to achieve the proper response are all part of extensive studies.

Color has long played an important psychological role in the aircraft community. For example, if the aircraft's Master Caution light begins to flash, is the color yellow significant to the required action? If this same caution light were white or green, would it have the same impact? The EJECT light is flashing red when activated. Would this light have the same effect if it were flashing green? It is apparent then, that color is essential in directing attention to a necessary action. Should not an equal amount of research be conducted on alerting devices for crewmembers deeply engrossed in high stress tactical workloads?

TEXT

The same factors which reflect a need for color alerts in cockpit displays are equally applicable to the tactical crew station. The use of multi-purpose displays in AASW has enhanced the integration and presentation of multiple sensor information. There are more than 20 possible display combinations available to the S-3 TACCO for use in any one tactical situation. Couple this

multiple sensor display capability with the high data rate of a computer and the tactical crew soon becomes overwhelmed.

Color is an effective and useful tool to the operator in a high stress situation requiring complete concentration. The technology necessary to fashion this tool into a useful instrument is available today.

Additionally, during the recent NSIA ASW Symposium, several speakers emphasized the point that new technology was not necessarily desirable, but improvements to current systems were greatly needed.

In this context, Lockheed and Loral initiated a research program utilizing independent funding in a cooperative effort directed toward the development of a multi-hue tactical color display. The product of this research is a color display that utilizes the existing S-3 hardware and requires a minimum of modification. The obvious advantage to this method is the savings in installation and logistic costs. The not so obvious advantage is that the reliability factor that is currently enjoyed by present displays is passed on to modified systems. Given the ability to economically modify present display systems to color, the next step is the proper application of this media to the ASW evolution.

The broad objectives of this program then, are to investigate the use of color to enhance and to simplify the display of tactical sensor data to the flight crew. Initial research indicates the following probable benefits from multi-hue displays:

a. Improved flight crew efficiency.
b. Reduced operator fatigue.
c. Reduced operator training requirements.
d. Improved sensor utilization.
e. Reduced operating costs due to improved operating efficiency.
f. Cost effective conversion utilizing existing hardware.

The Lockheed-Loral integrated color display system consists of a penetron CRT utilizing beam penetration of multi-layer phosphor to achieve three (3) colors. The color hardware is compatible with existing S-3 hardware and completely interchangeable. No additional cabling, power, or cooling is required and normal (green) displays will result from any mixture of monochromatic or color system components. Color is achieved only when all necessary system components are present.

Improvements in display system techniques and technology have the potential to reduce aircrew workloads and therefore, color coded alerting symbology applicable to ASW must be investigated.

The specific intent of this display development program is to investigate the effectiveness of color as a display coding technique in the ASW environment. Operational requirements for the next generation of manned airborne weapon systems dictate that the aircrews must have the ability to accurately assimilate a multitude of input data.

With the availability of a workable color system that has already been developed and tested, the display formats to be investigated may now be properly evaluated. An S-3 Integrated Bench Setup (IBS) is available at Lockheed's Rye Canyon Laboratory and it is ideally suited as a test vehicle to conduct this display format investigation. The laboratory has two (2) identical display positions similar to the display configuration in the S-3A and is therefore well suited to comparative format evaluation.

TACTICAL SCENARIO

An example of a tactical situation where color coding may be utilized as a warning device to aid the operator in decision making is depicted in Example A. Track 4002 represents a typical single color presentation with 4 fixes from RF's 1 and 2 as the basis for the computer generated track. The ranges from Ranger 2 have been updated and are current.

Example B demonstrates an identical tactical situation but range circles from Ranger 1 are aged amber after the first gate has been exceeded and red after passing the second time gate. The Track color is reflective of the probable inaccuracy of the fixes and therefore serves as a warning to the TACCO.

Example B/C is a composite where Track 4003 represents the true traget track and the phantom circles from Ranger 1 indicate actual ranges had update taken place.

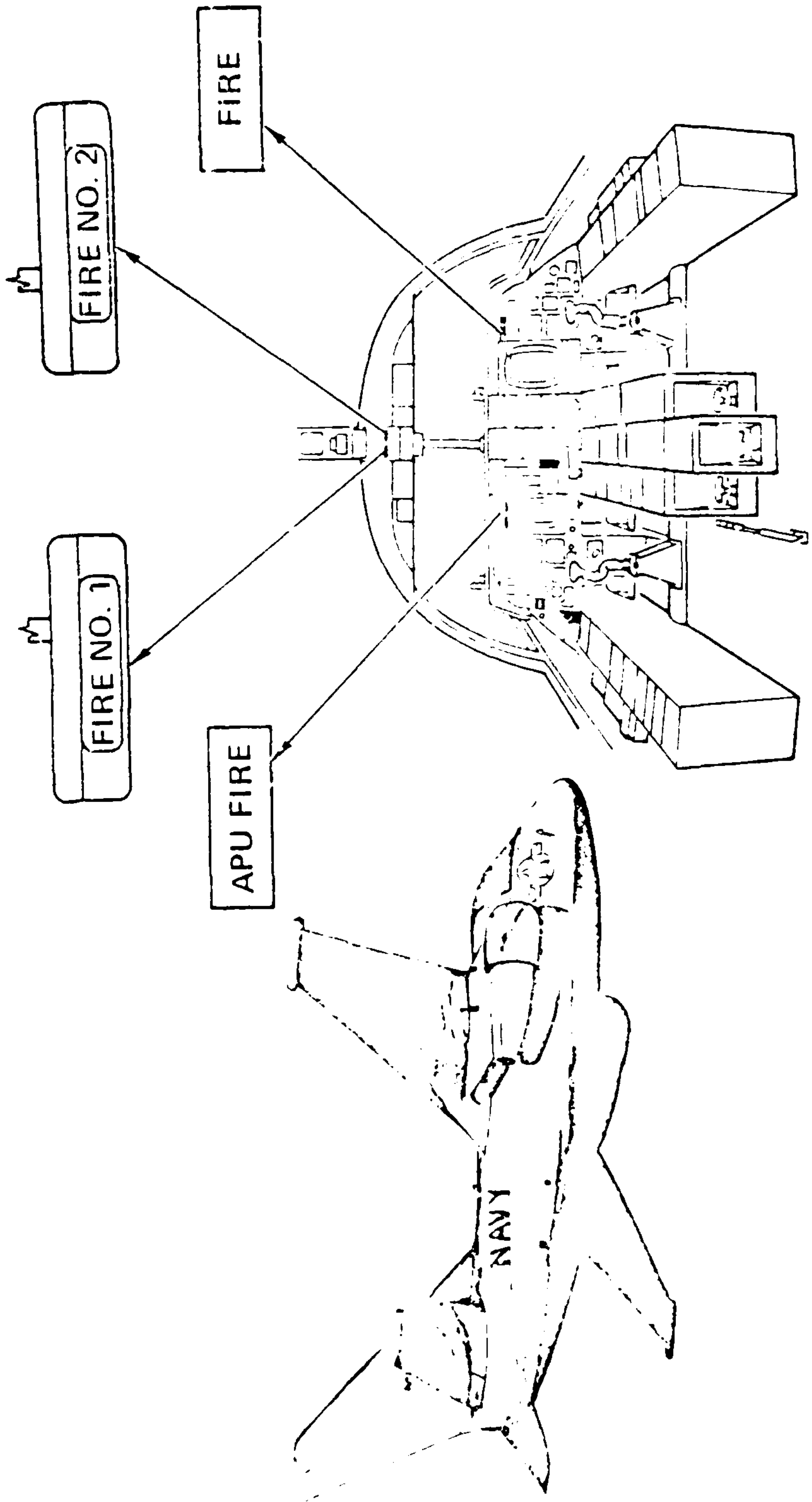
SUMMARY

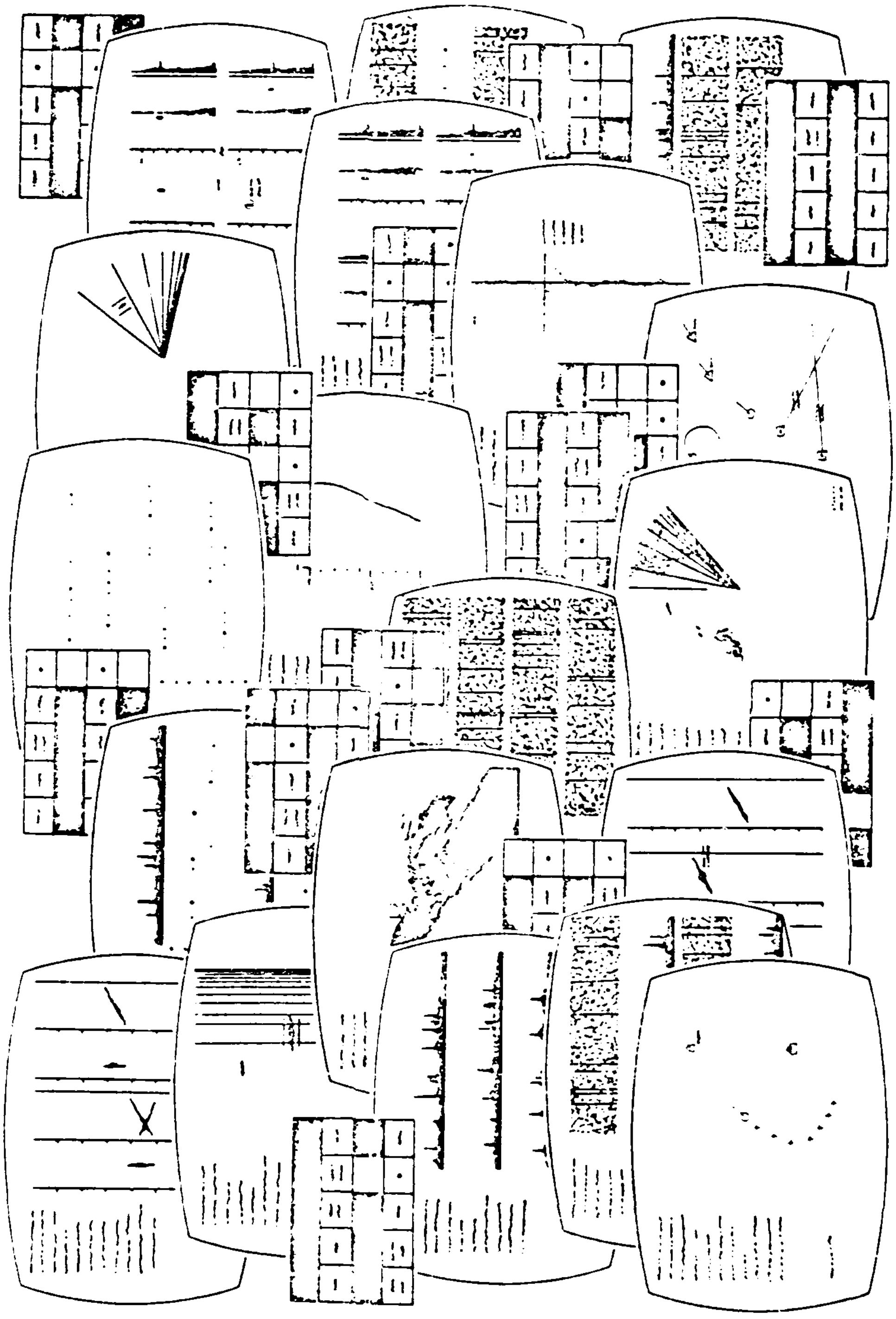
In summary, it must be said that color enhancement allows immediate perception of validity and thereby the potential to increase operator proficiency. All that remains is the development of useful symbology through research.

NAVY TACTICAL DISPLAY SYSTEM WITH COLOR

LOCKHEED
CALIFORNIA COMPANY

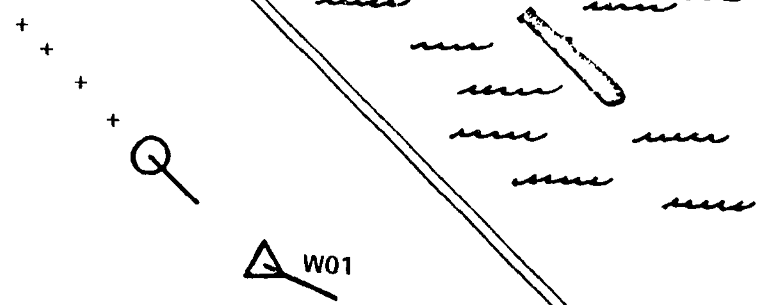
LORAL
ELECTRONIC SYSTEM


FIRE
FIRE NO. 2
FIRE NO. 1
APU FIRE
NAVY



Why Color in ASW?

- TACTICAL DISPLAY PROBLEMS SOLVED WITH COLOR
- FASTER AND MORE ACCURATE OPERATOR RESPONSE

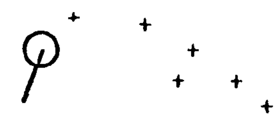


- LESS OPERATOR FATIGUE
- TECHNOLOGY IS AVAILABLE TO SUPPLY THESE NEEDS

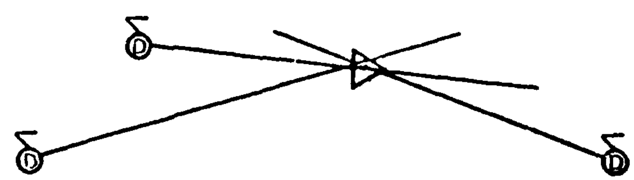
Benefits of a Navy Integrated Tactical Color Display

- IMPROVES FLIGHT CREW EFFICIENCY
- REDUCES OPERATOR FATIGUE
- REDUCES OPERATOR TRAINING REQUIREMENTS
- IMPROVES SENSOR UTILIZATION
- REDUCES OPERATING COSTS DUE TO IMPROVED OPERATING EFFICIENCY
- UTILIZES EXISTING HARDWARE FOR A COST EFFECTIVE CONVERSION

S-3A Color Display System



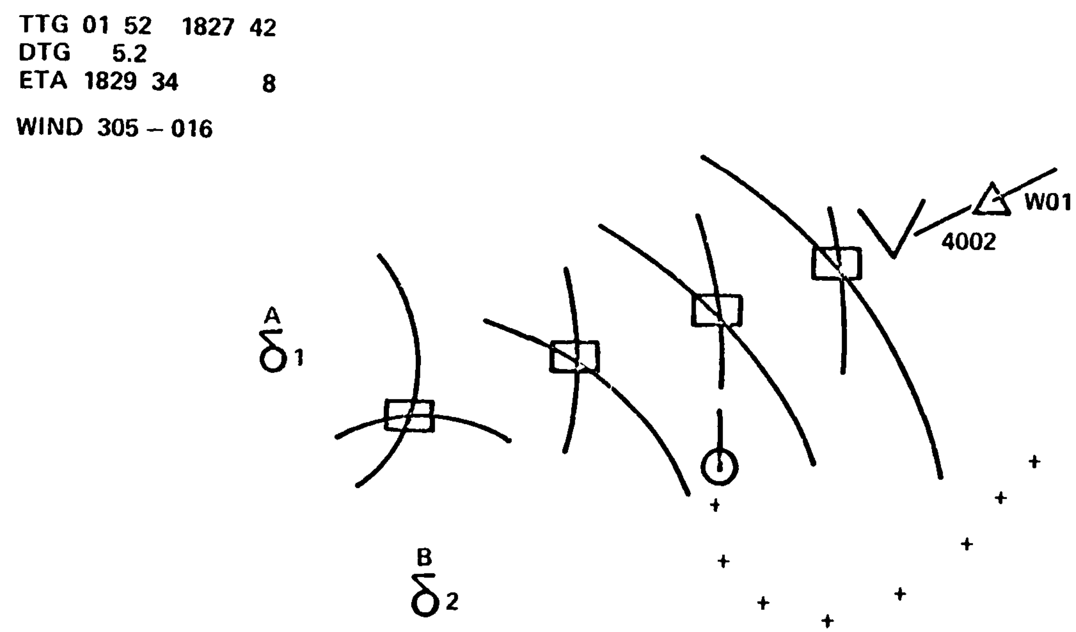
- THREE COLOR: RED, YELLOW, GREEN
- NO CABLING, POWER, COOLING OR INSTALLATION CHANGES REQUIRED IN S-3A
- COLOR HARDWARE INTERCHANGEABLE WITH PRESENT S-3A
- COLOR HARDWARE INSENSITIVE TO SHOCK, VIBRATION, UNITS AND STRAY FIELDS
- COMPATIBLE COLOR: ANY COMBINATION OF COLOR AND SINGLE
- COLOR, SOFTWARE/HARDWARE, WILL FUNCTION AS NON-COLOR



System Development

- INVESTIGATE
  - EFFECTIVENESS
  - CODING TECHNIQUES
  - FORMATTING
  - OPERATIONAL REQUIREMENTS
  - SOFTWARE
- EVALUATE
  - COLOR SYMBOLOGY
  - TACTICAL APPLICATION

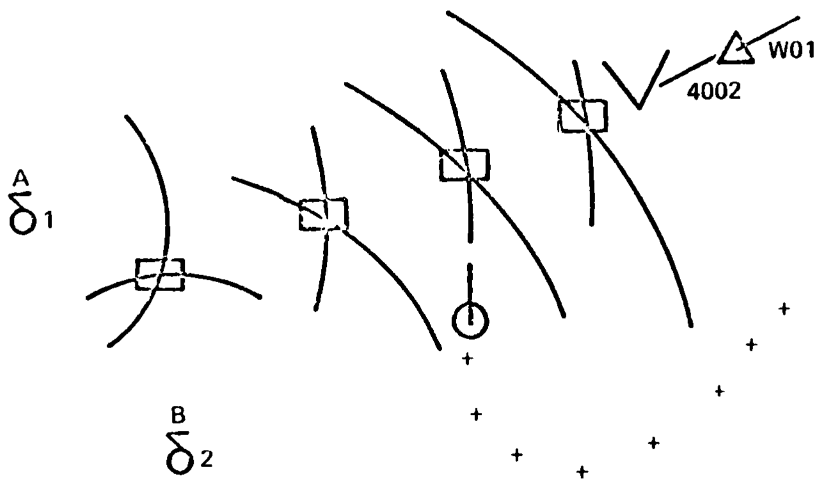
Tacco Steering Display



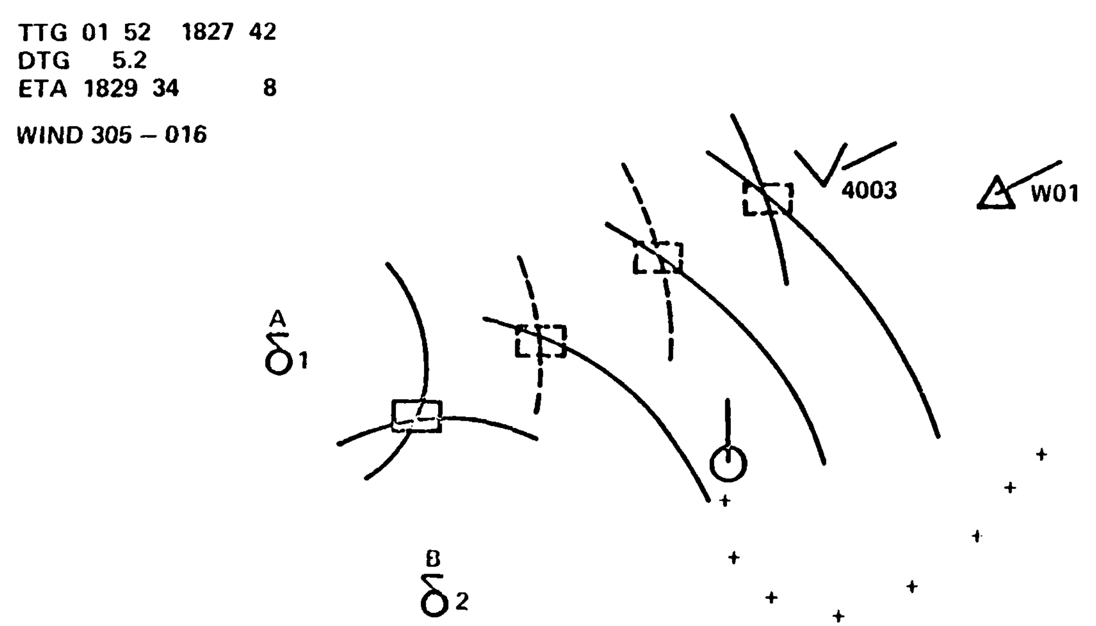
Tacco Steering Display

TTG 01 52   1827 42
DTG   5.2
ETA 1829 34   8

WIND 305 – 016



Tacco Steering Display



TACTICAL AIR APPLICATIONS FOR ADVANCED MULTISENSOR IMAGERY PROCESSING AND DISPLAY TECHNIQUES

E. L. Cloud
T. A. Stinnett
Westinghouse Defense and Electronic Systems Center
Baltimore, Maryland

ABSTRACT

Dynamic experimentation conducted by Westinghouse related to the real-time viewing of integrated multisensor (Infrared and TV) tactical imagery both in color and black and white and the application of display processing techniques such as level-slicing and surface differentiation have demonstrated that electronically processed multisensor imagery results in a significant reduction in operator response time and increased accuracy for target detection and recognition, as well as facilitating the assimilation of additional information content.

Of special significance is a measured decrease in operator variability when viewing integrated multisensor imagery as opposed to non-integrated imagery of identical scenes. From a squadron effectiveness viewpoint, reduced performance variability in conjunction with an improved mean of performance implies an increase in strike effectiveness. Tactical advantages realized include increased performance for detection and recognition tasks over a spectrum of targets and backgrounds, weather and climate, and various tactical situations.

INTRODUCTION

Fighter aircraft cockpit display and control and configuration requirements have historically been dictated by engineering rather than by pilot criteria. This situation is a logical one since most fighter cockpits evolve from highly technical engineering design efforts to advance the state of the art and are dependent on very sophisticated electro-mechanical display and control techniques. The tremendous acceleration of technical advancement affecting cockpit design in conjunction with reduced response times imposed by current and projected mission requirements presents a bewildering array of design variables. These include increased airframe performance capabilities, provision of multiple sensors and associated displays to extend the pilots' sensory capabilities, the provision of digital computers and microprocessors to increase his information processing capabilities, and the provision of multifunction controls to increase his response capabilities.

As if this design environment isn't complex enough, it is also one that is very subjective. Assemble 100 designers, engineers, and pilots, together to formulate a concept, and you'll extract 100 different opinions.

Human nature being what it is, the NIH (not invented here) factor is overwhelming.

With this setting in mind, we have addressed ourselves to presenting our concept of the implications of providing integrated multisensor imagery processing and display techniques to tactical air applications. In addition, we have expressed certain reservations toward embracing the assumed unconditional superiority of color versus black and white CRT display presentations.

At the risk of rocking some boats, we are somewhat dismayed to discover an apparent lack of consideration for the implications of incorporating imaging sensors on-board advanced fighters currently under and being contemplated for development. Whether this lack is due to an oversight or rather to an unawareness of the criticality of CRT display size as related to target detection and recognition is unknown. However, we would urge the people currently engaged in formulating future cockpit concepts and requirements to factor in the CRT display size consistent with imaging sensor capabilities and mission requirements as a critical variable in establishing cockpit configurations. If the pilot cannot visually resolve a target on the face of the CRT because of a limited display size, there is hardly any merit to be gained by providing a sensor capability to generate target imagery.

DEFINITION OF DISPLAY REQUIREMENTS

A very simple thought is that:

"Systems and machines are not created to serve themselves, they are created to serve man by extending his capability to

acquire or retrieve information,
to process information,
to respond."

This is so simple that many people tend to forget it. How many times have we experienced the engineer's delight, but the user's nightmare. Or, the software programmer who becomes so enamored with his program that he completely forgets the ultimate objective. In a tactical air combat environment, the pilot must acquire timely and accurate data that has been processed and displayed as information in a manner that enables him to exercise effective decision-making. We must think in context with such mission requirements as navigation to the target, target cueing, target acquisition and attack, and kill assessment and reattack. In conjunction with these requirements, we must consider display variables affecting the man-machine interface as shown in the table below.

TYPICAL INFORMATION DISPLAY VARIABLES

- Display Size
- Information Coding
- Alphanumerics
- Scale Legibility
- Visual Acuity Factors
- Modulation Transfer Functions
- System Resolution
- Flicker
- Brightness/Contrast
- Dynamic Range
- Environmental Variables
- Signal-to-Noise Ratio

Incorporating display variables into a system modulation transfer function (MTF) analysis provides only a partial solution to the man-display interface equation. Using an example MTF analysis as in figure 1, the analyst can evaluate subsystem factors such as the electro-optical sensor intensifier, the sensor tube optical train, display, and come up with a product MTF. But again this is an incomplete solution since the physiological properties of the human eye have not been considered.

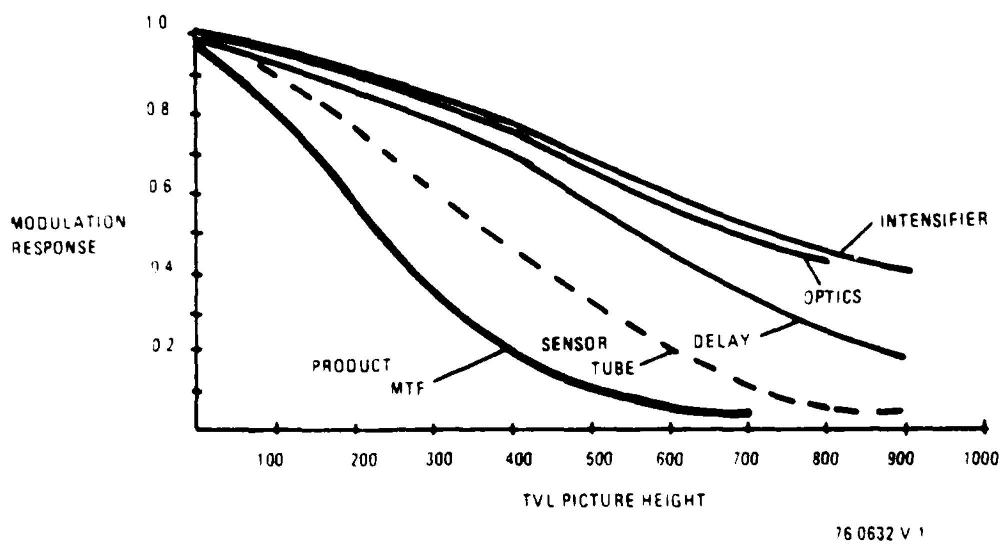
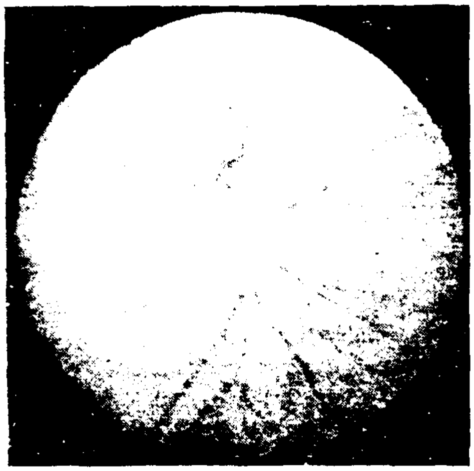
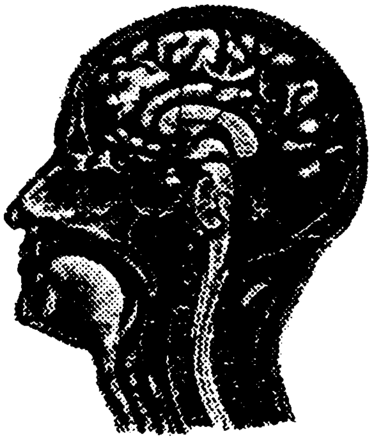


Figure 1. Example System MTF Analysis

The figure below is a photograph of the retina of a human eye. However, the equation is still incomplete since the most important subsystem of all, the human brain, must be considered.



Retina of the Human Eye



The Human Brain

This leads the analyst into the morass of human perception. The Mr. Tweedy cartoon shown below exemplifies this point very clearly and succinctly. Display information and the manner in which it is presented is very subjective. This is especially true when dealing with color.

In conjunction with personal biases for or against certain hues, the designer must consider brightness and saturation as well as the characteristics of the ambient illumination. Normal vision during daylight illumination is acquired by photopic vision, a condition where color sensitive cones in the retina of the eye generate visual sensations. During the dark of night, scotopic vision is provided by the highly light sensitive rods. When using colors, one must remember that they are strongly influenced by the characteristics of the surrounding background. Apparent sizes and shapes of targets can be altered by the allocation of different colors. They can be made to appear larger or smaller relative to the surrounding area as well as made to appear to present a higher or lower contrast relative to the surround.

To sum up, we are merely pointing out that it is very critical that the performance of a comprehensive display analysis be considered as a key task during the conceptualization of cockpit display and control requirements. And that such an analysis include consideration of mission objectives, flight profiles, sensor characteristics, display processing requirements, display mechanization characteristics, and human factors variables including human perception.

INTEGRATED MULTISENSOR IMAGERY PROCESSING AND DISPLAY

The following discussion is related to studies and experimentation conducted by Westinghouse in conjunction with USAF Contract No. F33615-69-C-1194 in 1969. It seems appropriate at this time to dust off this previous work and represent some of the important results since interest in acquiring combined multisensor imagery through a common aperture window seems to be reviving.[1] It is highly desirable that multiple electro-optical sensors share a common window to reduce aircraft weight and drag, as well as to provide common fields-of-view and to reduce misregistration problems. The state of the art for window materials compatible with TV and infrared has improved to the point where a common aperture is now foreseeable. Using a common window requires a material providing high transmission of both TV and infrared spectral bands with very low distortion. The window must withstand inclement weather and be inflexible with respect to air pressure or vibration.

The original multisensor program conducted at Westinghouse entailed acquiring integrated TV and infrared video by synchronizing an AGA Thermovision infrared sensor sensitive in the 3-5.4 μm spectrum with a Westinghouse vidicon TV camera (see figure 2).

[1] Faubert, D. B., and Leonard, K. C., Real Time Multisensor Data Display, paper presented at National Aerospace Electronics Conference, 18-20 May 1970, Dayton, Ohio. (In: NAECON 70 pp. 88-95)

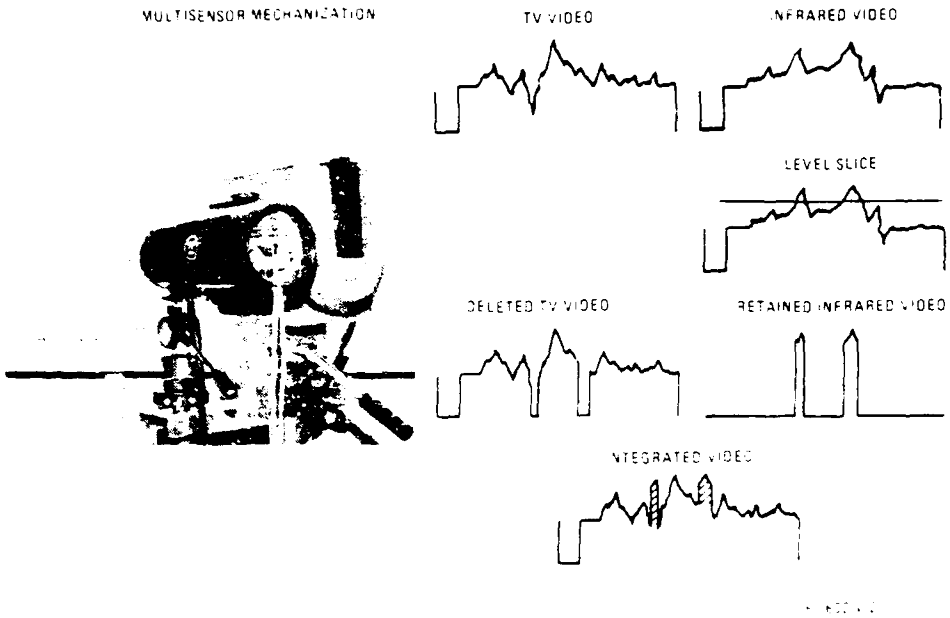


Figure 2. Multisensor Mechanization

Since TV and infrared spectral characteristics are dissimilar, it is logical to select the best output from each and integrate the video. It is important to realize that this is not an additive process or superposition; we are actually integrating TV and infrared into a common video.

Why is this desirable? From a tactical air viewpoint there are many advantages to be gained. A major aspect of weapon delivery system effectiveness is related to time-sensitivity as well as to accuracy. Therefore, particular attention must be devoted to the reduction of task loads to acceptable levels. This holds especially true for the single-seat fighter. The most critical response time variable is the decision as to which sensor at any given instant will provide the best image. Since spatial limitations prohibit provision of dedicated displays, it is obviously desirable to integrate the video from multiple sensors for presentation on a single display. Sequential viewing is undesirable due to the increased response time as well as the lack of a direct compariosn of sensor performance against any given scene condition at any given time. As shown in the air field video pictures of figure 3, integration of the two videos provides the best of both worlds.

In terms of integrating multisensor video, there are many processing techniques that can be incorporated to achieve display enhancement as well as video integration. The matrix shown in figure 4 represents a partial listing of enhancement techniques that we at Westinghouse have considered.

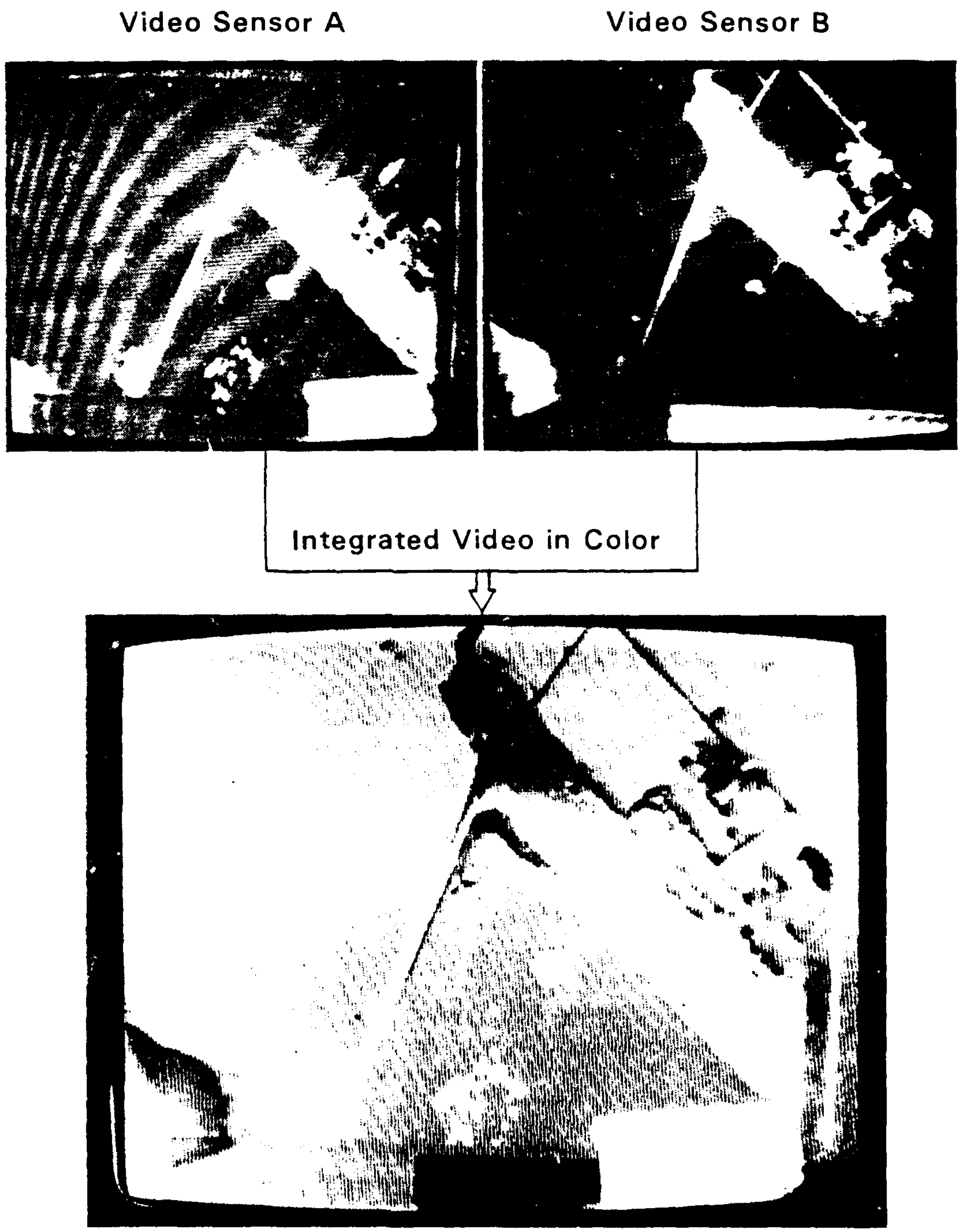


Figure 3. Integrated Video of an Airfield From Two Different Sensors

MODE	IR CONTROL: GAIN	IR: POLARITY	IR: EDGE-ENHANCEMENT CONTOUR FILL	IR: ARTIFICIAL GAMMA LEVEL SLICING	IR: GUNS	TV CONTROL: GAIN	TV: POLARITY	TV: EDGE-ENHANCEMENT CONTOUR FILL	TV: ARTIFICIAL GAMMA LEVEL SLICING	TV: GUNS	COMMENT
1	1.0	+	X	X	B&W	0	X	X	X	X	+ IR ONLY
2*	1.0	-	X	X	B&W	0	X	X	X	X	- IR ONLY
3	0	X	X	X	X	1.0	+	X	X	B&W	+ TV ONLY
4	1.0	+	SURFACE DIFFERENTIATE	X	B&W	0	X	X	X	X	OUTLINE IR ONLY
5	0	X	X	X	X	1.0	+	SURFACE DIFFERENTIATE	X	B&W	OUTLINE TV ONLY
6	0.5	+	X	X	B&W	0.5	+	X	X	B&W	+ IR + TV
7*	0.5	-	X	X	B&W	0.5	+	X	X	B&W	- IR - TV
8	0.5	+	X	X	RED	0.5	+	X	X	B&W	RED IR + TV
9	0.5	-	X	X	B&W	0.5	+	X	X	GREEN	- B&W IR + GREEN TV
10	1.0	+	X	SATURATE ABOVE 50%	RED	0.7	+	X	X	B&W	HIGHLIGHT HOT WITH RED IR
11	1.0	+	CONT FILL SATURATE TV FILL	X	B&W	1.0	+	TV FILL IN SATURATED IR	X	B&W	TV FILL INTO IR (POSSIBLE - TV FILL)
12	1.0	+	IR CONTOUR FILL	X	B&W	1.0	+	CONTROL FILL WITH "BLACK" TV	X	B&W	+ IR FILL INTO "BLACK" TV AREAS
13*	1.0	-	IR CONTOUR FILL	X	B&W	0	+	CONTROL FILL WITH "BLACK" TV	X	B&W	- IR FILL INTO "BLACK" TV AREAS
14	1.0	+	SURFACE DIFFERENTIATE	–	RED	0.8	+	X	X	B&W	+ IR OUTLINE IN RED + TV BACKGROUND
15	0.8	+	X	–	B&W	1.0	+	SURFACE DIFFERENTIATE	X	GREEN	+ TV OUTLINE IN GREEN + IR BACKGROUND
16	0	+	SURFACE DIFFERENTIATE	–	B&W	[illegible]	+	–	X	B&W	+ IR OUTLINE IN WHITE AGAINST FULL TV BACKGROUND
17	0	+	X	LEVEL SLICE IN TEMP	RED GREEN BLUE	[illegible]	X	–	X	X	FAKE COLOR IR
18	1.0	+	X	LEVEL SLICE IN TEMP	RED GREEN BLUE	[illegible]	+	DIFFERENTIATE	X	B&W	FAKE COLOR IR WITH VIDEO

* OPTIONAL

Figure 4. Partial Matrix of Multisensor Display Enhancement Techniques

Display processing techniques such as level-slicing, insertion, surface differentiation, flicker, alteration, polarity reversal, and red, blue, and green color combinations, present a multitude of modes. It is readily apparent that we face an enormously complex task in attempting to quantitatively evaluate all possible combinations. At the risk of being accused of applying unscientific techniques, we reduced this matrix to a more manageable level of seven modes by subjective evaluation of these modes and by the application of plain old "engineering judgment." We temper this statement with the fact that our judgement was based on extensive past experience with tactical electro-optical sensor usage and was not the result of pure personal opinion. The matrix in figure 5 shows the seven modes that were experimentally evaluated. Modes 1 and 2, TV alone and infrared alone, displayed in black and white were selected to provide a frame-of-reference for performance comparison. Mode 3 was merely the superposition of TV and infrared in black and white. Mode 4 level-sliced the infrared and inserted it as red video into a blue-green TV video. Mode 5 was identical except that the infrared insertion was flickered at 2 Hz. Mode 6 was identical to mode 5 except that the video was displayed in black and white. Mode 7 provided an alternation of nonintegrated TV and infrared video at a rate of 0.5 Hz. This mode was selected to provide some measure of the value of sensor display alternation on a single display if a common sensor window aperture was not available or if it was technically unfeasible to provide integrated video due to extreme sensor dissimilarities such as scan rates, fields-of-view, etc.

SENSOR / MODE	IR		TV		REMARKS
	B & W	COLOR	B & W	COLOR	
1	X				Baseline for IR alone Imagery
2			X		Baseline for TV alone Imagery
3	X		X		IR and TV superimposed
4		Red		Blue-Green	IR inserted into TV
5		Red		Blue-Green	IR inserted into TV and flickered at 2 Hz
6	X		X		IR inserted into TV and flickered at 2 Hz
7	X		X		Each individually alternated at 0.5 Hz

Figure 5. Display Modes Experimentally Evaluated

The multisensor experimental setup is schematically summarized in figure 6. A partially wooded area with interconnecting dirt trails which lay 1,800 to 3,400 ft from an overlooking 120-ft tower was selected to stage the experimental scenes. Three vehicle types were run over a series of selected routes at three different times of day. The video data were recorded at 16 frames per second linearly and in parallel on magnetic tape. In this way a permanent and perfectly repeatable raw video record of each scene was preserved.

These video tapes were then played at the experimenter's convenience in the laboratory at a relatively flicker-free 32 frames per second on a commercial three-gun, color phosphor CRT. Vehicular motion in the scenes was controlled to compensate for the rapid playback. A display mode processor was devised which allowed both cyclic and continuous differential amplification and differentiation of the videos. Cross-feed was possible on an adjustable threshold which provided for clear insertion of one video into the other, in addition to simple summing. Finally, a color selection gate was provided where either video could be directed to any single or combination of color guns in the monitor. Imagery was recorded at three different times of day to obtain differences in shadow size and reflected and emitted radiation effects. During each imagery collection session, pretarget and posttarget run photometric readings and isotherms were recorded to enable correlation of experimental results to environmental factors. A total of 42 observers, both flight and nonflight experienced, participated in the program.

The basic measures collected were response time and frequency of response for detection and recognition tasks. Two frequency measures were collected for each task; completeness and accuracy with the latter incorporating response error. The results of the experimental program strongly

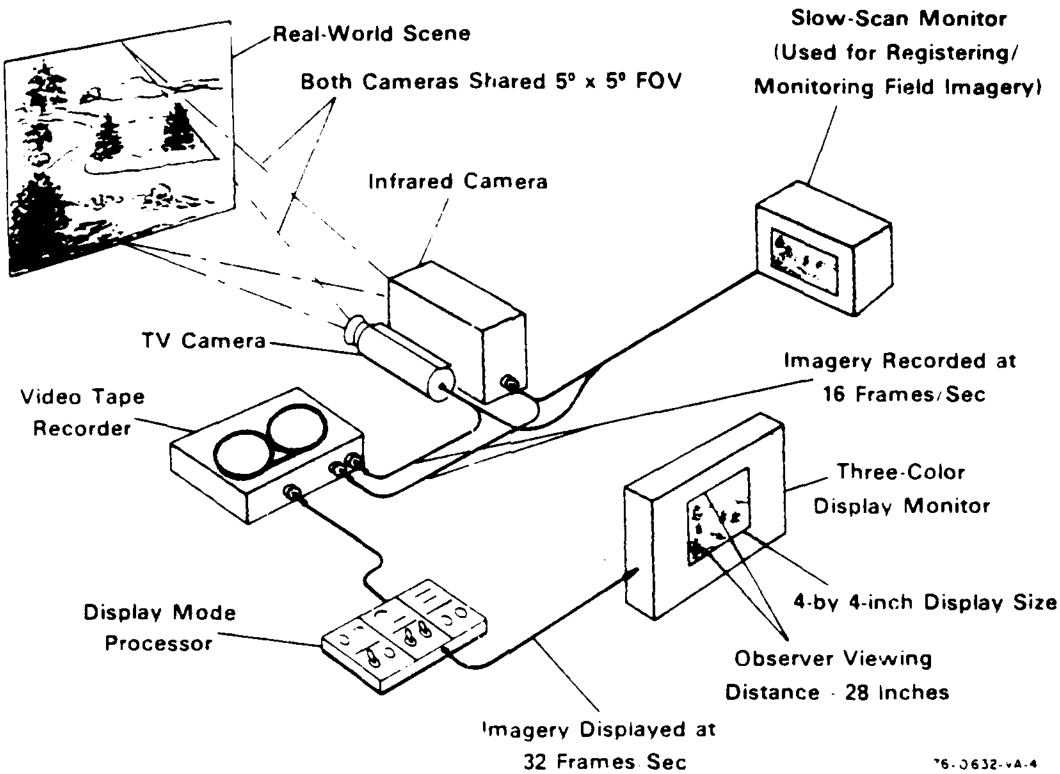


Figure 6. Multisensor Experimental Sensor, Recording, and Display Mechanization

indicate that integrated TV and infrared display imagery is far superior to single sensor presentations. This holds true for black and white as well as color display presentations. Differences in detection time responses are shown in figure 7. The color-coded mode with both TV and infrared continuously presented exhibited the best performance. This mode resulted in a reduction of 12 percent and 17 percent reduction in detection time over the TV and infrared modes respectively. The next best presentation was the block and white integrated mode with the infrared flickered at 2 Hz. It is interesting that the color-coded mode with infrared flicker resulted in a slower detection time than the infrared alone mode. We suspect that this can be attributed to the fact that stationary hot spots within the background exhibited apparent motion to the observer and were momentarily confused with a moving target. This apparent confusion somewhat reinforces our earlier statement that the nuances of human perception are very critical to incorporating the pilot into the sensor-processing-display equation. In terms of response time for target recognition, the integrated video in color and with the infrared flickered provided the best performance. The flicker mode provided a reduction in target recognition time of over five seconds and over nine seconds over the TV-alone and infrared-alone modes respectively. From a

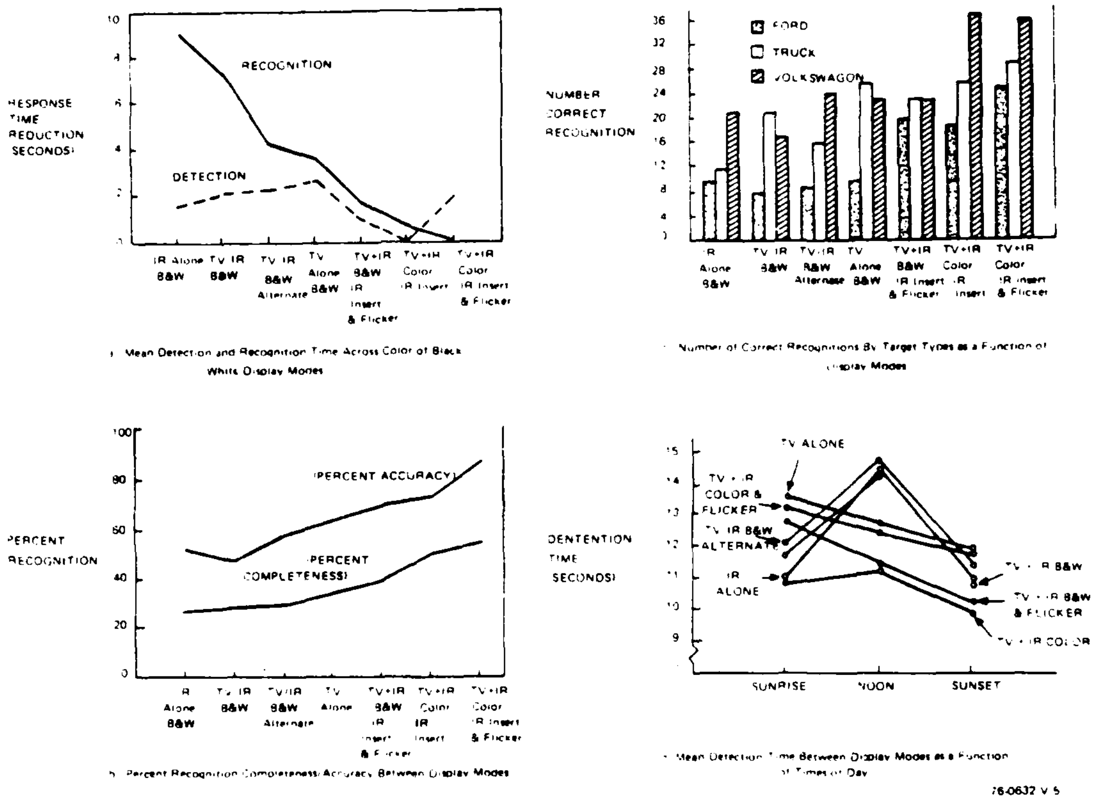


Figure 7. Experimental Results

tactical viewpoint where a few seconds in response time can result in success or failure, these data suggest significant value of the integrated video modes. Of special interest is a comparison of differences in performances for target detection compared to target recognition as a function of mode. While the integrated mode was better for detection it was not the best for recognition. The data for percent recognition completeness and accuracy show a parallel improvement in performance as compared to detection and response time. The color mode with flicker resulted in 56 percent complete recognitions compared to 27 percent and 35 percent for the TV-alone and infrared-alone modes. The color mode with flicker also resulted in the highest accuracy performance. This is highly critical from a tactical viewpoint since response error was incorporated and is indicative of false alarm rates. Only 12 percent false alarm recognitions occurred for this mode as compared to the TV-alone and infrared-alone modes. Of significant interest is the demonstration of differential performance as a function of display modes as related to target detection and target recognition tasks. Detection tasks do not necessarily correlate with recognition tasks. The best mode for target detection under specific conditions is not always the best mode for target recognition under identical conditions. Our results indicated that by switching from the continuous integrated color mode after target detection occurred to the flicker color mode recognition response time would have been improved 6 percent and recognition accuracy 14 percent. In addition, differential performance as a function of scene conditions as well as target type differences also occurs. It is readily evident that the establishment of criteria for the selection and employment of sensor-display modeology is even more complex than originally contemplated. When the allocation of false colors to display imagery is made, the situation becomes even more difficult. The photos in figure 8 illustrate this situation very effectively. Certain features of the airfield can be enhanced or subdued by the introduction of complementary and/or noncomplementary colors.

We have also experimented on a subjective basis with visual and infrared imagery mode available to us from the Defense Meteorological Satellite Program which is a Westinghouse developed sensor system for the Air Force on a space platform. Both sensors shared an identical field-of-view and provided simultaneous imagery relayed to Earth via data-link. Figure 9 shows Hurricane Ava which occured 6 June 1973 south of the Baja Peninsula. Notice the dissimilarities between the infrared imagery on the left and the visual imagery on the right even though they are identical scenes. As we begin level-slicing the infrared and integrating it into the visual, we can achieve some unusual effects. In this instance, the visual image was provided as a black and white reference. The infrared video was differentiated and pseudo-color coded. The sharply defined lines outline isotherms while the varying colors (shades of gray since this paper is printed in black and white) indicate coldest to warmest temperature

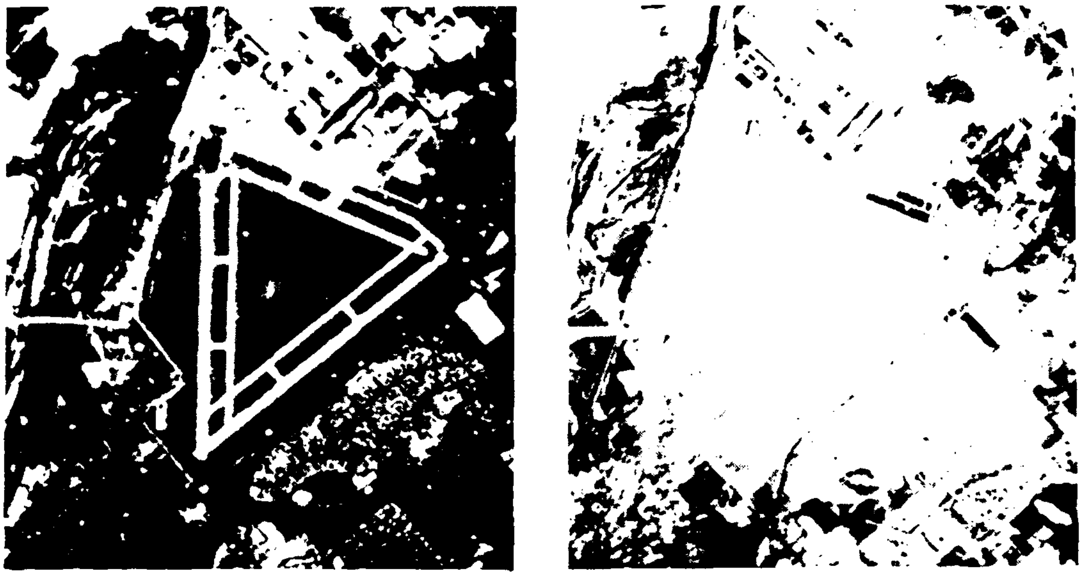


Figure 8. Allocation of False Color Is Very Critical to Enhancement or Degradation of Target Background Contrast

It is also apparent that the use of false color for imaging sensor displays does not always provide a superior picture. As shown, in an integrated image displayed in black and white, apparent resolution along contour differences is more pronounced than in the integrated image displayed in color. However, we have only subjectively evaluated these scenes and are not at this time prepared to substantiate this statement with quantitative measures.

IMPLICATIONS OF MULTISENSOR DISPLAYS FOR AIR-TO-MUD OPERATIONS

The dynamics of international politics in conjunction with certain domestic political pressures has created impetus for the desire and need for maximum flexibility of tactical capabilities and response. If the concept of limited warfare with associated constraints imposed by geopolitical parameters are relaxed, a "non-win" attitude reversed, and sophisticated command and control structures prove capable of graceful rather than catastrophic degradation, the provision of close-air support against targets such as tanks and artillery in close proximity to the FEBA will prove to be very critical to achieving victory on the battlefield. There might even be such things as targets of opportunity. The single-seat tactical aircraft of the HI-LO mix concept ranging from the sophisticated F-15, through the intermediate F-16/F-18 and to the austere A-10 presents serious implications for the achievement of flexible, effective weapons delivery operations.

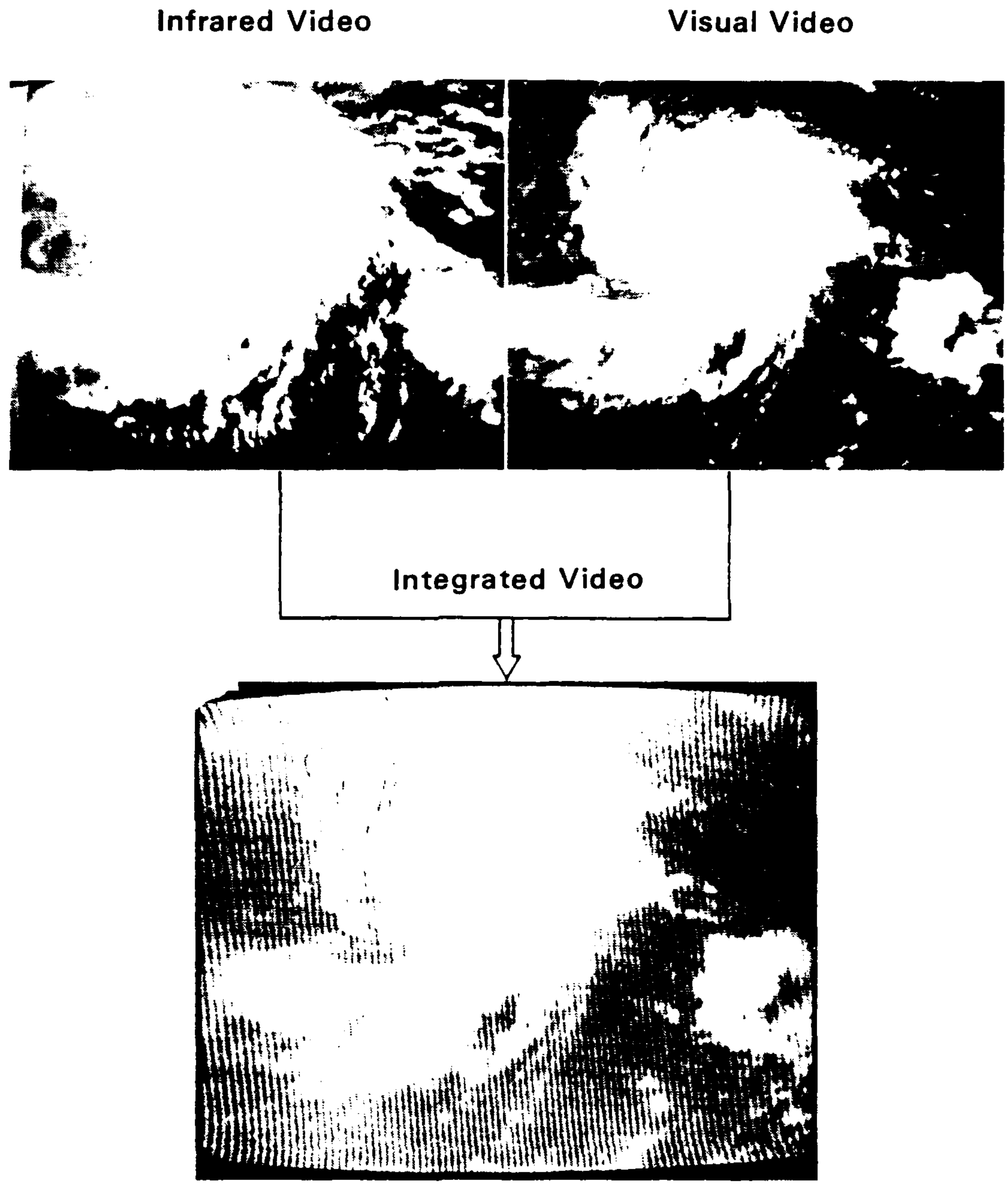


Figure 9. Visual Integration of Visual and Infrared Meteorological Imagery

These implications can be expected to be worse than projected when the tactical scenario is viewed from a flexible, response capability for air support strikes rather than the planned long-range interdiction missions that were prevelant in Vietnam. Efficient communications and coordination with ground-based and airborne FAC's as well as the ability to acquire and attack targets via self-contained sensors will be critical to mission success in such a dynamic combat environment.

"Able Fox Five to Able Fox 1 got a target but ya gotta be patient."

Figure 10. Flexible Response is Critical to Success in the Close-Air-Support Mission

At the risk of being accused of overconcern with mundane items in the cockpit, we point out that it is the simple and obvious problems that usually result in losing the battle. "For want of a nail...." Several examples that come to mind are the operational differences between radar and electro-optical sensors and the differences between synthetic and imagery display presentations. We have had the pleasure of conversing with many pilots who have had extensive experience with radar or electro-optical operations. Very few have had experience with both and the great majority had a "guy in back" who was the real sensor operation expert. The table below illustrates some of the basic differences related to pilot tasks.

Arguments always arise between people experienced in radar and electro-optical operations when trying to agree which direction the radar cursor should move along the range axis relative to moving the electro-optical sensor line-of-sight in elevation or depression angle. Radar cursor controls have historically been mechanized to push forward to increase range while electro-optical line-of-sight controls have been the reverse.

TYPICAL RADAR/ELECTRO-OPTICAL DIFFERENCES

Radar Cursor vs Electro-Optical Line-of-Sight Control

Scene Coverage Correlation

Radar Range vs Electro-Optical Field-of-View Selection

Display Format Differences

Aircraft Velocity Vector vs Display Orientation Stabilization

Synthetic vs Real Imagery

Symbols vs Imaging

A technical discussion (polite terminology for a heated argument) related to the virtues of stabilizing the display image relative to the velocity vector of the aircraft or to the vertical orientation of the displayed image almost always results in a lot of confusion and misunderstanding. And then there are the differences between synthetic symbology and imaging displays. They all present different characteristics and must be treated in accordance with these differences.

We must also encourage innovation in cockpit displays and controls to breakthrough the traditional way of doing things. This does not imply change for the sake of change but rather is intended to provide the performance required to meet new or projected mission requirements. For example, the radar map imagery shown in figures 11 and 12 is very recent. It is from a Westinghouse radar installed in an Air Force F-4D test bed currently bailed to Westinghouse. The range is approximately 25 nmi at an altitude about 7 kft. It occurred to us that it might be interesting to level-slice the video and reinsert it in real-time into the original video. This enables one to select for display only targets above, below, or falling within certain reflectance values. This mode can be displayed in color as well as in black and white. An immediate application that comes to mind is to simplify the radar display in SAC missions to enhance correlation with radar prediction charts. The crew is only interested in specific targets with certain reflectance characteristics. It seems logical to enable the crew to selectively eliminate or reduce targets and background returns of little or no interest at the display without sacrificing or reducing radar level of performance.

Figure 11. Radar Air-to-Ground Video

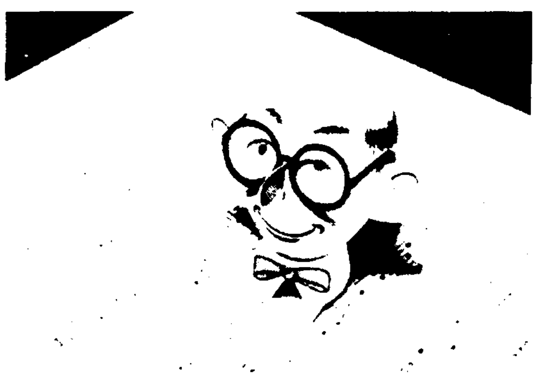
Figure 12. Radar Air-to-Ground Video Enhanced by Level-Slicing

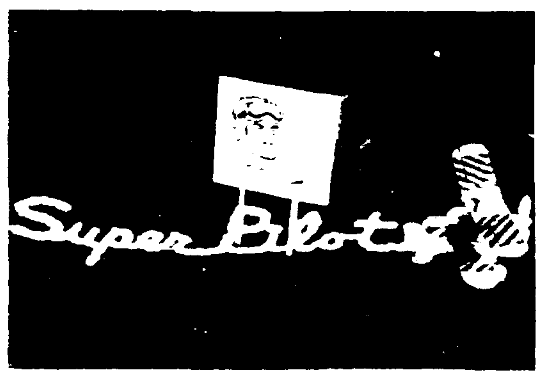
THE SUPER-ENGINEER/SUPER-PILOT SYNDROME

Everybody is an expert when it comes to displays and controls. And not necessarily only those displays and controls found in a fighter cockpit. This should not be surprising since displays and controls provide the interface between man and his machine. And human nature being what it is, this interface is usually very subjective if not downright emotional. Many of our experimental programs and man-in-the-loop simulations have demonstrated this situation. Structured questionnaires of subjective opinions related to observer confidence levels or how well they felt they performed a given task have not always directly correlated with actual performance. We have all experienced this feeling. "How did you do? Rotten!" Actually you turned in an outstanding performance using the new device.

At the risk of raising the hackles on the necks of some engineers and pilots, we have become sensitive to the super-engineer/super-pilot syndrome. It is very desirable to establish and maintain a meaningful dialogue between the highly specialized design engineer and the operational pilot.

Some super-engineers are oblivious to the pilot's operational requirements. As we stated early, he has forgotten that his wonderful machine has been created to serve man in a meaningful way. Super-pilot can fly the crate they came in. He can adapt to and surmount any handicap. Maybe he can. Unfortunately, the majority of us are not super-engineers or super-pilots. Our performance levels are distributed within a classic bell-shaped curve, which is usually well below those of super-engineer and super-pilot. We must think in terms of a squadron effectiveness viewpoint. No superstars win a war. It takes a team effort. We may not improve super-pilot's performance at all. Maybe he can fly the crate they came in. The same holds true for super-engineer. He may have created an engineering marvel that most average people can't operate. But if we can design and produce equipment that improves the performance of the rest of the team, we have accomplished something worthwhile.





ANALYSIS OF COLOR AND ITS EFFECTIVENESS

Richard E. Christ
New Mexico State University, Las Cruces, NM

Highly practiced subjects were used in a series of experiments to investigate the effectiveness of color coding relative to coding with letters, digits, and familiar geometric shapes. These experiments were concerned with unidimensional and bidimensional displays and with relatively simple single tasks (choice reaction, search and locate, and multiple target identification). The results were analyzed and are presented in a manner which will maximize their usefulness as a practical guide for when and where to use color in displays.

INTRODUCTION

A major consideration in display design has always been the selection of optimal symbolic coding variables. While a number of different coding variables have been extensively examined in the past, the relative efficiency of color as a coding variable has not been an issue until recently. Now however, advances in hardware technology have made color a highly feasible coding dimension. As a result of these hardware developments the question of whether or not to actually use color is being raised by both the manufacturers and the ultimate users of visual displays. Careful consideration of this question, however, raises at least two major qualifications.

First, it is important to distinguish among the several criteria that could be used to evaluate the relative value of color in displays. The technological or engineering aspects of putting color into displays is without question of considerable importance. While I am not qualified to address this aspect of the question, it seems safe to say that the cost and the

reliability and maintainability of color displays need to be established so that comparisons can be made between these color displays and more traditional achromatic displays.

The esthetic value of color is well established and is the one criterion which clearly favors the use of color. That is to say, almost any investigation of the value of color in displays which uses viewer preference as a criterion finds that the viewer believes color improves the quality of the display. Furthermore, when the issue is pursued, the viewer of color displays reports frequently that there is an improvement over black and white displays in information transfer from the display and in his ability to utilize this information.

Objective measures of the relative effects of color on operator performance, however, are much less consistent than the subjective reports of the operator. In fact, when one wishes to employ objective measures of operator performance as the criteria for judging the value of color in displays he is immediately confronted with a dearth of data and the information that is available is very inconsistent. A recent review of the relevant literature by Christ (1975) showed that even when subjects preferred color displays and even when they were convinced that color aided their performance, there was little or no objective data to support those subjective feelings.

Once one recognizes the diversity of criteria that can and indeed must be used to judge the relative effectiveness of color in displays, still another major qualification needs to be considered. Specifically, the question of whether or not color is better than achromatic or monochromatic displays must take into account the purpose of the display and the conditions in which it will be used. Displays are used in a wide variety of applications. The requirements of the display and the relative effectiveness of color may vary

AD-A097 285   NAVAL AIR TEST CENTER PATUXENT RIVER MD   F/G 5/8

ADVANCED AIRCREW DISPLAY SYMPOSIUM (3RD), 19-20 MAY.(U)

1976

UNCLASSIFIED   NL

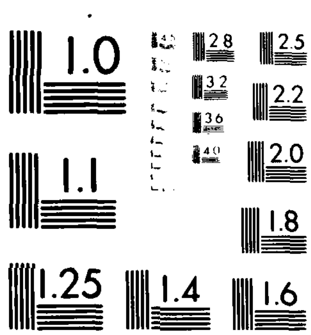
5 of 5

END

DATE FILMED

5 81

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

considerably as a function of the application. A recent review of the literature quantitatively analyzed the objective performance data from those few studies which could be used to determine the relative effectiveness of color codes. That review showed that color could be a very effective target code under some display and task conditions, but also that color could yield no advantage and might even be detrimental under other conditions relative to various types of achromatic codes.

Objectives of Present Research

Our own research is limited to examining the effects of color on objective measures of human performance. We have assumed the engineering aspects are either of no consequence or that they will be dealt with by those most qualified to do so. While recognizing the importance of operator acceptance we have also assumed that the operator of a complex system will accept and come to prefer those display parameters which can be shown to actually aid him in his need to acquire and utilize information presented in the display. Our research into the issue of color has also taken into account the issue of applications. Consequently, we have examined the relative effectiveness of color in a variety of different display and task conditions. Both relatively simple and more complex situations were employed, the latter analyzable into the simpler units from which they were constructed.

Our efforts were initiated and guided by the results of a quantitative review of the literature. While the information derived from the literature review permitted the generation of a tentative guide for the use of color in displays, an equally valuable outcome was the identification of those gaps in knowledge which have prevented a definitive evaluation of color coding. The major limitation of the published studies is the complete absence of data necessary for making some color versus achromatic code comparisons.

Furthermore those few comparative values which are available in the literature have generally been obtained under highly restricted conditions. Of particular importance, these restrictions include the fact that published experimental results are, with few exceptions, based on the performance of essentially unpracticed subjects, i.e., subjects who participated in one, usually short, experimental session. In addition, the published data were obtained under conditions in which subjects could devote their full attention to a single display for the purpose of accomplishing a single, relatively simple task. These two restrictions, more than anything else, severely limited the design guides that were established. (Christ, 1975).

The present report summarizes a series of experiments designed to provide a revised (where needed) and expanded table of gains and losses associated with the use of color in visual displays relative to achromatic coding variables. These experiments and the data and conclusions derived from them are fully discussed in a recently released technical report (Christ and Corso, 1975). The overall concern of most of these experiments was to provide a single group of subjects long-term practice with each of four coding variables (Letters, Digits, Familiar Geometric Shapes, and Colors) in each of three types of relatively simple tasks, Choice Reaction Time (CRT), Search and Locate, and Identify. Subsequent reports in this series will describe studies designed to determine the relative effects of color coding in more complex multiple task conditions.

GENERAL METHODOLOGY

The apparatus used for these studies consisted of a multiple display-multiple task system designed specifically for this research program. Since this system has been described in detail in an earlier report (Christ, Stevens, and Stevens, 1974), only a brief description will be given here.

The overall configuration of the displays and controls is illustrated in Figure 1 which shows a photographic view of the apparatus from over the left shoulder of a subject.

The displays used for the present series of experiments used IEE Series 00100 single plane rear-projection readouts. Each IEE unit consists of 12 projection lamps and 12 film messages. When one of the lamps is lighted it illuminates the corresponding film message, focuses it through a lens system, and projects it onto a non-glare viewing screen.

The display console used for all 10 experiments reported here was designed to hold one large multiple stimulus display and three smaller single stimulus displays. The large multiple stimulus display is shown in Figure 1 in the center of the display console. This display consisted of 16 IEE single plane readouts arranged in a 4x4 matrix. This matrix display was mounted behind a common viewing screen. While all six of the smaller peripheral displays shown in Figure 1 were visible to the subjects in this series of experiments, only those three at the bottom of the display console were used and then, no more than one at a time. Only the single IEE unit on the extreme right was used in Experiments 1, 2, 3, 8, and 10. Only the large matrix display was used in Experiments 4 and 5. The single IEE unit in the center of the row and the matrix display were used in Experiments 6 and 7. The single IEE unit on the extreme left and the matrix display were used in Experiment 9.

The same film was used in all of the IEE readouts relevant for any given experiment. The design of the films made it possible for all projected messages to be coded identically (unidimensional display) or for the messages to be coded by two coding variables (bidimensional display). Figure 2 presents examples of these two types of display conditions as they applied to the matrix display. It may be seen that the displays labeled B and D in Figure 2

are unidimensional shape and unidimensional letter displays, respectively. The displays labeled A and C in Figure 2 are bidimensional digit-shape and bidimensional letter-color displays, respectively. The messages in each display were lighted and shown against a dark gray background. Roscolene color filters were used in conjunction with the dots shown in the display labeled C in the figure.

The control console shown in Figure 1 consisted of four clusters of buttons. Each cluster of buttons was designed to receive a subject's responses for a different task. The six IEE units and associated buttons in the upper right corner of the control console were used to identify stimuli in the CRT and Identify tasks.

The Search and Locate response units consist of four momentary contact buttons arranged in a two x two matrix which was placed in the lower left corner of the control console shown in Figure 1. The subject used this response unit to specify the location (quadrant) of a target in the matrix display. The keyboard and buttons in the center of the control console shown in Figure 1 were removed from the console and that area was covered by an aluminum panel. The six buttons in the upper left of the control console were left exposed to the subjects but they were never used.

The entire system shown in Figure 1 was interfaced with a PDP8/e minicomputer. The software developed for this computer controlled all programmable sequences of display events. The experimental program and up to 100 stimulus sequences of 20 to 48 trials each were written onto one auxiliary magnetic tape (Dectape) and the responses and response times of the subject were stored on a second tape.

Except for Experiment 2, the same set of eight male subjects was used in all experiments. These subjects were paid a fixed sum per experimental

session for their participation and were also given a monetary incentive based upon their performance. All subjects were between the ages of 19 and 24, and they were all right-handed. In addition, subjects all had a visual acuity of at least 20/15 in each eye as measured with the Snellen chart and normal color vision in each eye as determined by the American Optical H-R-R Pseudoisochromatic Plates.

RESULTS

The results of these experiments were analyzed in terms of absolute levels of performance for each coding dimension and in terms of the effectiveness of color relative to the achromatic codes. Since these results are presented in considerable detail in the Christ and Corso (1975) technical report, only a few very salient results will be presented here.

The overall effects of practice and target codes on absolute levels of choice reaction time performance are illustrated in Figure 3. The choice reaction task was the only task which was run over extended series of practice sessions and which permits a thorough examination of the effects of practice and familiarization. The task employed was called a simple CRT task in that only one stimulus was presented on each trial. There was no uncertainty about when or where the stimulus would appear and there were no distracting or potentially interfering stimuli presented anywhere in the display console.

The data shown in Figure 3 were derived from one experiment which used four groups of relatively naïve, short-term subjects (Experiment 2) and from a series of experiments which used a single group of highly committed, highly practiced, long-term subjects (Experiments 1, 3, and 8). It may be seen that, in general the reaction times were quite long for the naïve subjects in Experiment 2. Statistical tests showed that the performance of all four groups of

of those subjects improved with practice and that there were large and consistent differences among the four target code conditions that were assigned to the four groups of subjects. The data from the single group of long-term subjects used in Experiments 1, 3, and 8 also show large effects due to practice, both within and between experiments. It is clear from these data that the absolute differences among target code conditions decreased over successive experiments for those long-term subjects.

Since the primary purpose of the present effort was to quantify the gains or losses associated with the use of color relative to achromatic codes, absolute measures of performance were used to calculate relative scores. The derived scores also enable comparisons among speed and accuracy criteria of performance and comparisons among the different types of simple tasks. The most relevant derived scores were computed by determining the difference between performance with color and with an achromatic stimulus as the target code and dividing this difference by the results obtained with the achromatic code, i.e.,

$$\text{\% Difference Score} = \frac{\text{Achromatic-Color}}{\text{Achromatic}} \times 100. \quad (1)$$

These calculations were based on data obtained from each individual long-term subject and were always made within a given experiment when all other task parameters were held constant. Positive scores indicate an advantage of a color, negative scores a disadvantage of a color, both relative to a particular achromatic target code.

Table 1 shows the minimum and the maximum gain (or loss) that was found with color as a target code relative to each achromatic target code. These percent difference scores are shown separately for each type of task. The scores for the choice reaction and the search and locate tasks are based upon correct response time measures. The scores for the identification task are

based upon both the average correct response times and the average levels of accuracy.

When the subject's task is to identify a single target as rapidly as possible, color produced relative losses in choice reaction time as large as -16 percent and relative gains as great as +36 percent. These percent difference scores varied as a function of the comparison achromatic code and as a function of whether the target stimulus appeared in isolation or in a field which also contained other nontarget background stimuli. The largest losses occurred when the target was presented by itself; the largest gains when the target was presented in a visually noisy (heterogeneous) stimulus display.

The use of color in search and locate tasks generally leads to a relative decrease in search/locate time. The gain in performance relative to when achromatic targets are used may be as great as 27 percent but there may also be a loss in performance as great as -8 percent. The greater gains are more likely to occur for the more dense displays (i.e., for displays containing many stimuli) and in bidimensional displays. The relative advantage of color is least for low density unidimensional displays.

When the subject is required to identify multiple targets from a briefly exposed display, color is less effective as a target code relative to achromatic stimuli if the primary objective is to maximize the accuracy of the responses. However, if the average correct response times are of primary importance, color coding leads to superior performance relative to letters, digits, or shapes. The effects in either case are never very large. The greatest relative loss associated with color for accuracy was only -17 percent; the greatest relative gain in the mean correct response times was about +27 percent. The larger relative scores were obtained with bidimensional displays; smaller scores were obtained with unidimensional displays.

CONCLUSION

In conclusion, it appears that color is most likely to benefit performance in any task if the subject must deal with more complex, multiple stimulus formats and when he must distinguish one class of stimuli (e.g., one stimulus dimension) from another. Presumably, color aids the subject in the requirement for organizing or reorganizing inputs from the display.

The results of this research program also emphasize the importance of practice with any coding variable and with any task. Even when the different coding dimensions led to relatively large difference in performance, there was a tendency for practice to attenuate the differences. Finally, even when there were relative differences in performance attributable to color, it is not certain that color was the only coding variable or the best coding variable that could produce those results. In these present experiments familiar geometric shapes produced performance measures quite similar to that found for color. It is certainly possible to conceptualize other types of achromatic or monochromatic coding dimensions, not tested here, which should be evaluated relative to color before potentially costly decisions are made.

It is critically important to remember that the ultimate criterion for deciding whether or not to introduce a change in the design of a display is not how "nice" something looks or how technologically sound something is, but, rather, how much it will enhance total system performance. The objective performance of the human operator is very often the limiting factor in the performance of the total system. Consequently, I strongly urge that in addition to engineering feasibility studies, and in addition to subjective preference studies, more engineering psychology studies be completed (and required) before display design changes are implemented. Only then can decisions about when and how to change displays be considered meaningfully against such other

system requirements as cost, training, and the like.

REFERENCES

Christ, R. E. Review and analysis of color coding research for visual displays. Human Factors, 1975, 17(6), 542-570. (Also published as a Final Report, NMSU-JANAIR-FR-73-1, JANAIR Report 730703, July 1973, NTIS No. AD-767066).

Christ, R. E., & Corso, G. M. Color research for visual displays. (NMSU-ONR-FR-75-1, ONR Report CR213-102-3), Las Cruces, New Mexico, New Mexico State University, July 1975.

Christ, R. E., Stevens, A. C., & Stevens, D. Color research for visual displays (NMSU-JANAIR-FR-74-1, JANAIR Report 741103). Las Cruces, New Mexico, New Mexico State University, July 1974.

TABLE 1

Range of Percent Difference Scores for the Use of Color[a]

Comparison Achromatic Code	Choice Reaction Task (Time)		Search/Locate Task (Time)		Identification Task (Time)		Identification Task(Accuracy)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Letters	-11.8	+36.5	- 7.8	+27.3	+ 5.8	+27.4	-17.0	+ 2.9
Digits	-16.0	+29.2	- 6.7	+21.9	- 9.7	+17.3	-15.0	+ 0.2
Shapes	- 6.8	+16.4	- 2.8	+12.9	- 0.1	+15.7	-13.1	+ 1.1

[a]Positive scores indicate a gain, negative scores a loss with the use of color.

Figure 1. The apparatus as seen over the left shoulder of a subject.

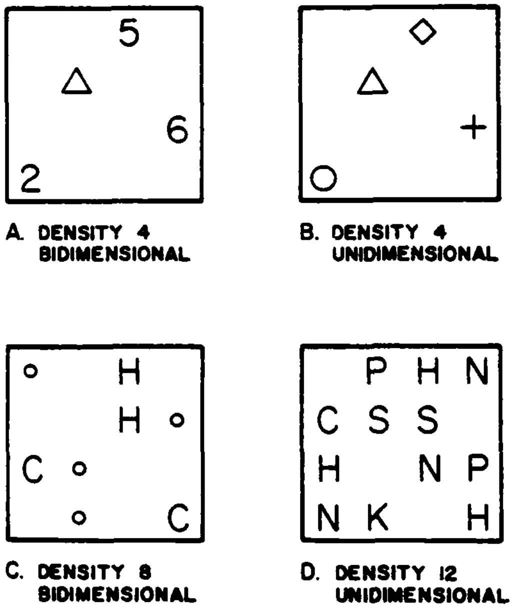


Figure 2. Examples of the types of matrix displays used.

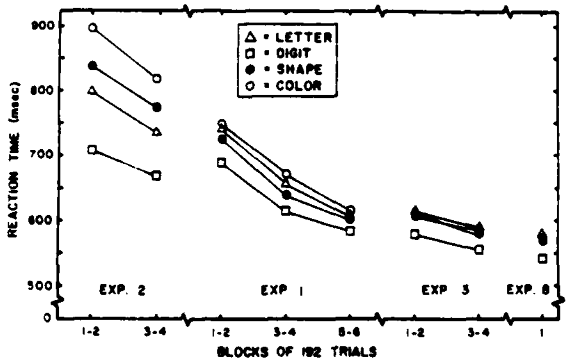


Figure 3. Reaction time as a function of practice and target code.

ADAM, E. G.

McDonnell Douglas
1501 Cervlean Drive
St. Louis, Missouri 63141
314-232-4890

AHRENS, Ralph

Sperry M/S E-2
Great Neck, New York 11767
516-724-1226

ALDRICH, R. G.

Interstate Electronics Corp.
P. O. Box 3117
707 East Vermont Avenue
Code 4610
Anaheim, California 92803

ALEXANDER, J. C.

Computer Devices Co.
P. O. Box 8508
Ottawa, Ontario, Canada KIG3M9
613-596-3060

AMEEL, LCDR F. D.

Safety Officer
Naval Air Test Center, Staff
Patuxent River, Maryland 20670
301-863-4248

ANDERSON, LT David W.

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4424

ANTHONY, James F.

Fairchild Republic Co.
Conklin Street
Farmingdale, New York 11735
516-531-2664

BAALS, CDR J. R.

Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4576

BABCOCK, Gary L.

Airline Pilots Association
1329 E. Street NW
Washington, D. C. 20004
202-797-4198

BAILEY, William

Northrop Corporation
1701 North Fort Meyer Drive
Arlington, Virginia 22209
703-525-6767

BALDWIN, George F.

General Electric Co.
Aerospace Elec. Dept.
French Road MD 218
Utica, New York 13503
315-797-1000 (Ext. 7820)

BALOG, Ronald J.

Clifton Precision
5100 State Road
Drexelhill, Pa. 19026
215-MA2-1000

BARILE, Tony

Bendix Corporation - FSD Division
Route 46
Teterboro, New Jersey 07608
201-288-2000

BARNETTE, James F.

USAF/FC
Randolph Air Force Base,
Universal City, Texas 78148
512-652-4114

BATEMAN, Robert P.

USAF Flight Dynamics Lab
AFFDL/FGR
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-3708

BEATTY, James M, Jr.

Box 3951
Nellis Air Force Base
Las Vegas, Nevada 89191
702-643-2443

BEGGS, Elizabeth B.

Naval Air Systems Command
AIR-360
Washington, D. C. 20361
202-692-2510

BEILMAN, John L.

Calspan Corporation
Box 235
Buffalo, New York 14221
716-632-7500 (Ext. 497)

BENTON, Stephen A.

Polaroid Corporation
750 Main Street - LA
Cambridge, Mass. 02139
617-864-6000 (Ext. 3357)

BERG, Al

Hughes Aircraft Co.
6/C106
Culver City, Ca. 90230
213-391-0711 (Ext. 4432)

BERGMAN, H. B.

Cardion Electronics
Long Island Expressway
Woodbury, New York 11797
516-921-7300

BERTHOT, Russell

Naval Air Systems Command
AIR-570
Washington, D. C. 20361
202-692-0751

BJELLAND, Harley

Conrac Corporation
1600 S. Mountain Avenue
Duarte, California 91010
213-359-9141

BLOOMSTRAN, F. David

Raytheon Company
528 Boston Post Road
Sudbury, Mass. 01776
617-443-9521 (Ext. 2641)

BONADIES, Al

Telcom Systems, Inc.
2300 South 9th Street
Arlington, Va. 22204
703-979-8300

BOUDREAU, W. H.

Smiths Industries Inc.
1444 Steward Blvd
Clearwater, Florida 33516
913-531-7781 (Ext. 233)

BOWEN, Don

Sundstrand Corp.
Suite 1111
600 New Hampshire Ave. N.W.
Washington, D. C. 20037
202-965-4650

BOYD, Robert W.

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4211

BRAULT, Y.

Thomson - CSF
178 Boulevard Gabriel Peri
Malakoff, France 92240

BRENNAN, W. T.

Collins Avionics Division
Mail Station 120-110
Cedar Rapids, Iowa 52402
319-395-4588

BROWNING, Douglas

Technical Support Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4854

BRUCE, George I. C.

Ferranti Ltd
Edinburgh, Scotland
031-332-2424

BUNTING, Russ

Photo-Sonics Inc.
820 S. Mariposa Street
Burbank, California 91506
213-849-6251

BURKE, Joseph E.

Vought Corporation
Unit 2-54220
P. O. Box 5907
Dallas, Texas 75222
214-266-4737

BURNS, J.

Dumont Corporation
750 Bloomfield Avenue
Clifton, New Jersey 07015

BUSTLE, Lawrence E., Jr. LTCOL

USAF
Pentagon Building
Washington, D. C. 20361
301-287-2324

BURTON, Gardner T.

RCA MS 5-1
P. O. Box 588
Burtington, Mass. 01803
617-272-4000 (Ext. 3480)

CALHOUN, Ms Gloria L.

Bunker Ramo Corporation
P. O. Box 3058
Dayton, Ohio 45431
513-254-2647

CAMERON, James S.

Naval Air Test Center
Rotary Wing Aircraft Test Direc.
Patuxent River, Maryland 20670
301-863-4436

CAMPBELL, J.

Marconi Elliott Avionic Systems Ltd.
Airport Works
Rochester, Kent, England

CAREL, W.

Hughes Aircraft Corporation
Culver City, California 90230
213-391-0711 (Ext 4686)

CARPENTER, MAJ John H.

USAF/IFC RD
Randolph Air Force Base
Universal City, Texas 78148
512-652-4114

CASSIDY, Floyd M.

Micro-Switch
1766 Old Meadow Road
McLean, Virginia 22101
703-790-3381

CHAMPOUX, Robert L., LCDR

OPTEVFOR/VX-1
Naval Air Station
Patuxent River, Md. 20670
301-863-3771

CHORLEY, R. A.

Smiths Industires Limited
Aviation Division
Cheltenham, Glos. England

CHRIST, Richard E.

New Mexico State University
P. O. Box 5095
Las Cruces, New Mexico 88003
505-646-1334

CHURCHWELL, MAJ John E.

ASD/AES (JTIDS)
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-3127

CIZNER, Allen

Norden Division of UTC
Helen Street
Norwalk, Conn. 06856
203-838-4471

CLOUD, Eugene L.

Westinghouse Electric Corp.
P. O. Box 746 MS 440
Baltimore, Maryland 21203
301-765-6252

COLLINSON, RPG

Marconi-Elliott Avionic Systems Ltd
Airport Works
Rochester, Kent, England

CONLEY, P. W.

Jet Electronics & Technology, Inc.
5353 52nd Street
Grand Rapids, Michigan 49509
616-949-6600

COOPER, George H. V., Esq.

Naval Air Systems Command
AIR-5105A
Washington, D. C. 20361
202-692-8571

CORRELL, Robert D.

Hermetic Aircraft Inst. Corp.
200 Marine Street
Farmingdale, New York 11735
516-694-6780

COYLE, Thomas F.

Naval Air Test Center
Computer Services Directorate
Patuxent River, Maryland 20670
301-863-4473

COYLE, William

Piper Aircraft Corporation
Lock Haven, Pa. 17745
717-748-6065

CUDAHY, Colonel

Head, AFAL/AA
Wright Patterson Air Force Base
Dayton, Ohio 45433

CUOMO, Salvatore N.

Westinghouse Elec. Corp.
P. O. Box 1897
Baltimore, Md. 21203
301-765-3421

CURRLIN, O. G.

Cardion Electronics
Long Island Expressway
Woodbury, New York 11797
516-921-7300 (Ext 222)

D'AMATO, Leonard P.

Computer Services Direc.
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4046

DAVIES, Don

Bendix Instruments & Life Support Dn
Hickory Grove Road
Davenport, Iowa 52806
319-324-9101

DAVIS, Gregory A.

Technical Support Direc.
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4473

DAVIS, William B., Jr.

Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D. C. 20590
202-426-8605

DeCELLES, Larry

Airline Pilots Association
9107 Lee Boulevard
Leawood, Kansas 66206
913-381-3145

DeMARCO, Emanuele

Clifton Precision
5100 State Road
Drexel Hill, Pa. 19026
215-436-8127

DeRUYCK, A. R.

Polhemus Navigation Sciences, Inc.
P. O. Box 1011
Burlington, Vermont 05401
802-863-5595

DeTHOMAS, S. V.

ASW Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4101

DICK, Al

Behavioral Research
622 Harvard Street
Rochester, New York 14607
716-442-5861

DOUGHERTY, Capt. Gerald P.

Naval Air Systems Command
AIR-03PAA
Washington, D. C. 20361
202-692-7444

DOWD, Chuck

Grumman Aerospace
13 Roberta Lane
Commack, New York 11725
516-LR5-7186

DRESEL, David L.

USAF Avionics Lab
AFAL/AA DAIS ADPO
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-4822

DUNLEAVY, CDR Richard M.

Office of Chief of Naval Operations
OP-506H
Washington, D. C. 20350
202-694-9004

EDWARDS, Dr. Alan M.

A-T-O Inc.
1911 Jefferson Davis Highway
Arlington, Virginia 22202
703-920-8990

ELIASON, Major Dan

USAF Aero-Medical Lab
AMRL/HEC
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-3438

ELLIS, James O.

Carrier Systems Branch
Strike Aircraft Test Direc.
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4644

ENDERWICK, Thomas P.

COPOPTEVFOR
Code 224
Norfolk, Virginia 23452
804-444-5197

EVANS, L. D.

Lockheed-California Co.
P. O. Box 551
Burbank, California 91520
213-847-2321

FAIR, George

Rockwell-International
Los Angeles A/C Division
Los Angeles, California
213-670-9151 (Ext. 3413)

FASSEL, D. J.

Sundstrand Data Control
Overlake Industrial Park
Redmond, Washington 98052
206-885-8362

FEIGHTNER, E. L.

General Electric Corp.
2009 N. 14th Street
Suite 101
Arlington, Va. 22201
703-527-3065

FENDLEY, John N.

Westinghouse Elec. Corp.
P. O. Box 746, M/S 277
Baltimore, Maryland 21203
301-765-4604

FIELDS, Wallace

The Boeing Company
P.O. Box 3999, M/S 7968
Seattle, Washington 98124
206-655-4910

FISHER, Ed.

Clifton Precision
5100 State Road
Drexelhill, Pa. 19026
215-622-1000

FOOTE, CDR E. W.

COMNAVAIRLANT
Code 332
Norfolk, Va. 23544
804-444-4321

FROHMANN, Jules

Loral Electronic Systems
999 Central Park Avenue
Yorkers, New York 10704
914-968-2500

FUENTES, Al

P. O. Box 383
Lexington Park, Maryland 20653
301-863-9667

FULLER, William

Norden
Helen Street
Norwalk, Conn. 06856
203-838-4471

GALLAGHER, Jim

IBM
Owego, New York 13827
607-687-2121

GANGAWERE, L. B.

Westinghouse Electric
P. O. Box 1897 MS 701
Baltimore, Maryland 21203
301-765-2466

GEISELHART, Richard

USAF Aeronautical Systems Div.
7604 S. Swan Lake
Dayton, Ohio 45424
513-236-6161

GELLES, Rubin

Austin Electronics
450 W. First Avenue
Roselle, New Jersey 07203
201-241-3300

GEIGER, Anson D.

Honeywell, Inc.
1611 N. Kent Street
Arlington, Virginia 22209
703-524-8200 (Ext. 247)

GIBSON, P.

Ferranti Ltd
Plainview, New York 11803
516-337-2442

GILLESPIE, Ray L.

General Electric Company
3 Penn Center
Philadelphia, Pa. 19002
215-568-1800

GRAHAM, David

The Boeing Company
NASA Langley Research Center
M/S 264
Hampton, Virginia 23665
804-827-2511

GRALOW, R.

Norden Division/United Technology Corp.
Helen Street
Norwalk, Conn. 06903
203-838-4471

GREEN, Harold

Naval Air Development Center
Code 30421
Warminster, Pa. 19152
215-OS2-9000 (Ext. 2029)

GREENE, Tom

Naval Air Test Center
Systems Engineering Test Direc.
Patuxent River, Md. 20670
301-863-4157

GREENLEE, W. E.

Naval Air Test Center
Strike Aircraft Test Directorate
Patuxent River, Md. 20670
301-863-4226

GRIFFIN, John Henry

Norden Division/United Technology Corp.
Helen Street
Norwalk, Conn. 06903
203-838-4471

GUTTORMSON, Donald L.

Rosemount, Inc.
P. O. Box 35129
Minneapolis, Minn. 55435

HANFORD, Ransom B.

Technical Support Direc.
Naval Air Test Center
Patuxent River, Md. 20670
301-863-4151

HANSON, Donald C.

Office of Naval Research
800 N. Quincy Street
Arlington, Va. 22217
202-692-4420

HARDT, Charles J.

Strike Aircraft Test Direc.
Naval Air Test Center
Patuxent River, Md. 20670
301-863-4424

HARPER, Howard P.

Sikorsky Aircraft Division
United Technologies
Stratford, Conn. 06602
203-378-6361 (Ext. 1266)

HARPER, Tom L.

Vought Corporation
P.O. Box 5907
Dallas, Texas 75222

HARSE, W. H.

General Dynamics
Forth Worth Division
P. O. Box 748
Fort Worth, Texas 76101
817-732-4811 (Ext 2177)

HARTNELL, Desmond

The Boeing Company
NASA TCV Program
P. O. Box 7005
Hampton, Virginia 23666
804-827-2511

HASTBACKA, Albin

Sanders Associates
Nashuz, New Hampshire 03060
603-885-6022

HATTERSHIRE, Bond R.

USAF/AFFDL/FGR
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-233-8660

HEDGER, Donald L.

Sperry Flight Systems
P. O. Box 21111
Phoenix, Arizona 85036
602-942-2311 (Ext. 1624)

HELLER, F. P.

Marconi Elliott
Airport Works
Rochester
Kent, United Kingdom

HERRON, Sam

Bunker Ramo
P. O. Box 3058
Dayton, Ohio 45431
513-254-2647

HEWKO, Al

Safe Flight Instrument Corporation
P. O. Box 550
White Plains, New York 10602
914-946-9500

HILL, Stan

Kaiser Aerospace
1651 Page Mill Road
Palo Alto, California 94306
415-493-3320

HILLIARD, Milton

Westinghouse
Rt. 1. Box 147C
Millers, Maryland 21107
301-765-4604

HICKS, T. A.

Computing Devices Company
MS 3-11-E
Box 8508
Ottawa 4
Ontario, Canada KIG3M9
613-596-4879

HITCHCOCK, Dr. LLoyd

Naval Air Development Center
Code 402
Warminster, Pa. 18974
215-672-9000 (Ext. 2191)

HITE, CDR P. R.

Office of Naval Research
800 N. Quincy Street
Arlington, Va. 22217
202-692-4421

HITCHCOCK, Harold R.

NAILSC
Naval Air Station
Patuxent River, Md. 20670
301-863-5220

HOLT, James D.

NASA
MS 152D
Hampton, Va. 23665
804-827-3871

HOOPER, Arthur W.

Technical Support Direc.
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4151

HOOVER, George W.

Northrop
746 Alma Real Drive
Pacific Palisades, California 90272
213-454-9608

HOOVER, Wayne

Computer Services Direc.
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-3710

HURLEY, James T.

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4226

IDE, Charles H.

General Electric
Box 5000
Binghamton, New York 13902
607-748-4184

JABLONSKI, Edward

Cardion Electronics
Long Island Expressway
Woodbury, New York 11797
516-921-7300 (Ext. 203)

JAMES, John E.

Kaiser Aerospace & Electronics
1681 Page Mill Road
Palo Alto, California 94306
415-493-3320

JESSEN, RADM George E.

Asst. Commander for Mat'l Acquisition
Naval Air Systems Command
Washington, D. C. 20361
202-692-3827

JOHNSON, James E.

DMAAC
St Louis, Missouri 63118
314-268-4871

JOHNSON, Jim LCDR

Naval Air Systems Command
Washington, D. C. 20361
202-692-7488

JONES, W. Roy

Pilkington P.E.
Glascoed Road
St. Asaph CLWYD
N WALES 9B
UK 0745 583301

JORDAN, David L.

General Electric
Aerospace Instruments Prod. Dept.
Wilmington, Mass. 01887
617-267-4771

KAPINOS, Steven A., Sr.

Computer Services Direc.
Naval Air Test Center
Patuxent River, Md. 20670
301-863-3334

KEARL, A.

Boeing Commercial Airplane Co.
Renton, Washington 98055
206-237-9355

KEARNS, John H.

U.S. Air Force
AFFDL/FGR
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-3708

KEELY, Captain L. B.

Head, CV Aircraft Design,
Naval Air Systems Command
Washington D. C. 20361
202-692-8726

KELLY, Daniel R.

Raytheon Co.
528 Boston Post Road
Sudbury, Mass. 01776
617-443-9521 (Ext 2794)

KELLY, Captain G. R. (retd)

6451 Fairland Street
Alexandria, Va. 22312
703-354-7791

KELVIN, Allan E.

Grumman Aerospace Corp.
Life Sciences
Department 474, Plant 35
Bethpage, New York 11714
516-575-2701

KENDALL, Ken

Bendix Corporation
Rt 46
Teterboro, New Jersey 07608
201-288-2000

KENWORTHY, Ken

USAFTFWC/TE
1556 Ottawa Drive
Las Vegas, Nevada 89109
702-643-4030

KERKERING, Kenneth J.

USAF/IFC
218 Grey Cliff
San Antonio, Texas 78233
512-656-1736

KILTZ, Richard M.

Sundstrand
Overlake Indus. Park
Redmond, Washington 98052
206-885-8489

KIMBLE, Joe

Cerebonics, Inc.
5600 Columbia Pike
Falls Church, Va. 22041

KING, William J.

Naval Air Systems Command
Washington, D. C. 20361
202-692-0754

KIRKPATRICK, John H.

OASN (R&D) Navy Department
Washington, D. C. 20361
202-695-6913

KLOPFSTEIN, Colonel

French Air Force
Boulevard Victor 26 Paris 15
France

KOPFMAN, Theodore F., Captain

CO, Training Squadron TWENTY-SIX
Quarters "J" NAS Chase Field
Beeville, Texas 78103
512-354-2273

KNOX, Carl E.

Rockwell International, Columbus A/C Div.
195 Andalus Drive
Gahanna, Ohio 43236
614-239-3204

KRAFT, LCDR J. N.

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Md. 20670
301-863-4844

KROUSE, Lynn

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Md. 20670
301-863-4713

KULWICKI, Philip V.

USAF - 6570 AMRL
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-3029

LAI, Guy W.

USAF Aernautical System Division
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-4400

LAMLEY, G. A.

Smith Industires, LTD
Aviation Division
Cheltenham, Glus. ENGLAND

LARKIN, D. H.

Jet Electronics & Technology, Inc.
Suite 306, Crystal Plaza #1
2001 Jefferson Davis Highway
Arlington, Va. 22202
202-628-4380

LaRUE, James D.

Logicon, Inc.
4134 Linden Avenue
Dayton, Ohio 45432
513-258-8100

LAVIN, Herb

General Electric
MD-399 French Road
Utica, New York 13501
315-SW7-1000

LAWRENCE, Melvin

Mitre Corporation
Westgate Research Park
McLean, Virginia 22101
703-790-6845

LAWTON, Burtis

Venus Scientific Inc.
61 Monterey Circle
Lavallette, New Jersey 08735
516-293-4100

LEE, CDR Bobby

VA 147
C/O FPO
San Francisco, Ca. 96601
209-998-3054

LENG, A. J., LCDR

Naval Safety Center
Norfolk, Va. 23511
804-444-7926

LEET, Louis H.

USAF/AFFDL/FGR
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-3708

LESLIE, John C.

VX-5
Naval Air Station
China Lake, California 93555
714-939-5244

LESTER, Dr. J. T.

Office of Naval Research
ONR 495 Summer Street
Boston, Mass. 02210
617-426-8329

LEWIS, C. J. S.

E. A. Industrial
4500 N. Shallowford Road
Chamblee, Georgia 30341

LINE, Martin

CONRAC Corporation
1600 S. Mountain Avenue
Duarte, California 91010
213-359-9141

LOFTUS, John

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4424

LOHMANN, Robert A.

Hughes Aircraft
Centinella and Teale Streets
Los Angeles, California 90274
213-391-0711 (Ext. 4103)

LOIKITH, Gary

Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4157

LOUIS, E. J.

General Electric
French Road, MD 218
Utica, New York 13503
315-979-1000

LOUSMA, LTCOL Jack

NASA - JSC
Code CB
Houston, Texas 77546

LUCKA, W. A. (USAF)

Chief, Crew Station Escape Branch
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-2840

MALECKI, Gerald D.

Office of Naval Research
800 N. Quincy Street
Arlington, Va. 22217
202-692-4505

MALHERBE, Gerard

French Ministry of Defense
DTCA/STAE
15 Chester Street
Cambridge, Mass. 02140
617-661-7594

MALONEY, Brian

Lundy Electronics & Systems
21 Brewster Street
Glencove, New York 11542
516-671-9000

MANN, Robert C.

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4176

MARCUS, Melvin A.

Norden Division
United Technologies Corporation
Helen Street
Norwalk, Connecticut 06856
203-838-4471

MARTIN, John C.

Sikorsky Aircraft Corp.
N. Main Street
Stratford, Conn. 06602
203-378-6361 (Ext. 653)

MARTIN, Joseph R.

Raytheon Co.
528 Boston Post Road
Sudbury, Mass. 01776
617-443-9521 (Ext. 2641)

MASTERS, George W.

USN Test Pilot School
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4061

MATTHEWS, Dr. A. R.

Naval Air Test Center
Chief Scientist
Patuxent River, Maryland
301-863-4421

McBRIDE, Elmer A.

General Electric Co.
777 14th Street NW
Washington, D. C. 20005
202-637-4297

McCLEARY, Robert J.

Raytheon Company
400 Army Navy Drive
Arlington, Virginia 22202
703-979-6100

McCORMICK, Daniel

Photo-Sonics Incorporated
5403 Country Club Drive
North Carolina
919-674-9842

McCOY, W. K.

IBM
Marketing
Owego, New York 13827
607-687-2121 (Ext. 3259)

McELVEIN, David B.

Kollsman Instrument Co.
Daniel Webster Highway
Merrimack, N.H. 03054
603-889-2500

McLAUGHLIN, William J.

Dumont Electron Tubes
750 Bloomfield Ave.
Clifton, N.J. 07015
201-773-2000

MERCHANT, John

Honeywell Radiation Center
Massachusettes
617-862-6222

MERLIN, A. G.

Loral Electronics
1911 Jefferson Davis Highway
Arlington, Va. 22202
703-920-5606

MERRIMAN, Stephen C.

Naval Air Systems Command
AIR-5313A1
Washington, D. C. 20361
202-692-7488

MICALI, J. A.

Kollsman Instrument Co.
Daniel Webster Highway South
Merrimack, N.H. 03104
603-889-2500 (Ext. 2210)

MIEDZYBRODZKI, L. R.

Ferranti Ltd.
Edinburgh
Silverknoves
Scotland, UK
031-332-2424

MILLS, G. S.

McDonnell Aircraft Co.
Department 354
Building 33
Level 6, Post 635
P.O. Box 516
St. Louis, Mo. 63166
314-232-2762

MITCHELL, LCDR C. S.

COMNAVAIRPAC
Code 311L
Naval Air Station
North Island
San Diego, California 92135
714-437-6129

MOORE, Ron

Conrac Corporation
330 Madison Avenue
New York, New York 10017
212-687-3330

MORGENFELD, Thomas A., LCDR

Air Test and Evaluation Squadron Four
Naval Air Station
Pt. Mugu, California 93042
805-982-8796

MORONEY, LCDR William

Pacific Missile Test Center
Code 1242
Pt. Mugu, California 93042
805-982-8981

MORRISSETTE, Dick

Honeywell Inc.
Massachusettes
617-862-6222

MURPHY, J. J.

Cardion Electronics
Long Island Expressway
Woodbury, N.Y. 11797
516-921-7300 (Ext. 263)

MYSING, John

AFAL/AAT
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-4858

NELSON, CAPT Jack H.

Office of Naval Research
495 Summer Street
Boston, Massachusettes 02210
617-426-1909

NESTEL, John

Consolidated Airborne Systems
895 Waverly
Holtsville, New York 11742
516-654-3200

NICE, Jerald A.

Naval Air Development Center
Code 5514
Warminster, Pa. 18974
215-672-9000 (Ext. 2139)

NOFZIGER, L. B.

Naval Air Development Center
Warminster, Pa. 18974
215-672-9000 (Ext. 2111)

NOTLEY, T. J.

Ferranti Limited
Crewe Toll
Edinburgh, Scotland
031-332-2411

ODA, Donald J.

Lockheed California Co.
2509 E. Avenue R-3
Palmdale, California 93550
213-847-1450

OLSEN, J. J. CDR

Naval Air Test Center
DIRTESTACT, NAVAIR 6104, Bldg 437
Patuxent River, Maryland 20670
301-863-4801

PADGETT, LCDR J.

Naval Air Test Center
Test Pilot School
Patuxent River, Maryland 20670
301-863-4417

PACE, Charles M.

Norden Division
United Technology Corporation
1125 15th Street, NW
Washington, D. C. 20005
202-785-7498

PALMA, LCDR R. J.

Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, Md. 20670
301-863-4171

PARADIS, Peter R.

Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4151

PAYNE, Phillip E.

USAF Avionics Laboratory
AFAL/RWT-1
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-6550

PEGG, Richard W.

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4211

PENNEY, N.W.

Smith Industries Ltd
1444 Steward Blvd
Clearwater, Florida 33516
813-531-7781

PERNOT, Gerard

French Military Division
French Embassy
2164 Florida Avenue NW
Washington, D. C. 20008
202-332-8300

PETRALE, John J.

Loral Electronics Systems
999 Central Park Avenue
Yorkers, New York 10704
914-968-2500

PICKERING, Jerry A.

General Dynamics
Mail Zone 2402
P. O. Box 748
Fort Worth, Texas 76101
817-732-4811 (Ext. 3643)

POLHEMUS, W. L.

Polhemus Navigation Science
Box 1011
Burlington, Vermont 05464
802-863-3595

PUMA, LTCOL Samuel C.

USAF/USN Exchange
601 Ticonderoga
China Lake, California 93555
714-939-5216

REDFOOT, Lyle John

NAVELEX, U.S. Navy
Washington, D. C. 20361
202-692-8924

REGAN, Joseph F.

Raytheon Company
465 Centre Street
Quincy, Ma. 02169
617-479-5300 (Ext. 273)

REISING, John M.

USAF/AFFDL
AFFDL/FGR
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-5520

REYNOLDS, Charles L.

Sperry Flight Systems
P. O. Box 21111
Phoenix, Arizona 85036
602-942-2311 (Ext. 694)

RHODES, Bill

Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4116

RICHARDSON, W. T.

Northrop Corporation
1800 Century Park
Los Angeles, Ca. 90067
213-970-4726

ROCH, Donald R.

Kaiser Aerospace & Electronics
1681 Page Mill Road
Palo Alto, California 94306
415-493-3320

RODGERS, Allan G.

Polhemus Navigation Sciences Inc.
P. O. Box 1011
Burlington, Vermont 05401
802-863-5595

ROSCOE, Stan

Hughes Aircraft Co.
Building 6
MSD-120
Culver City, California 90230
213-391-0711 (Ext. 3768)

ROVER, Richard

Bendix Corporation
Route 46
Teterboro, N.J. 07608
201-288-2000

RUFFING, CAPT Richard E.

Wright Patterson Air Force Base
Dayton, Ohio 45433
514-255-3777

RULIFFSON, J. J.

Navy Fighter Weapons School
Naval Air Station Miramar
San Diego, California 92145
714-271-3444

RUNIEWICZ, Walt

Clifton Precision
Pennsylvania
215-622-1000

RUTHERFORD, Jr. Robert

Dumont E.D. Corp.
750 Bloomfield Ave.
Clifton, N.J. 07015
201-773-2000

RYAN, George R., Jr.

Naval Air Test Center
Technical Support Directorate
Patuxent River, Maryland 20670
301-863-4151

SABO, A. E.

Lundy Electronics
21 Brewster Street
Glencove, New York 11542
516-671-9000

SANDLER, LCDR C. E.

Naval Safety Center, Code 1213
Norfolk, Va. 23511
804-444-7927

SANDUNSKY, R. R.

Northrop Corp.
1800 Century Park
Los Angeles, Ca. 90067
213-970-3812

SAVITSKY, Thomas E.

Raytheon Co.
528 Boston Post Road
Sudbury, Mass. 01776
617-443-9521 (Ext. 2641)

SCHELHORN, Arno E.

Calspan Corporation
Box 235
Buffalo, New York 14221
716-632-7500 (Ext. 337)

SCHIFLETT, Dr. Samuel

Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4157

SCHWAAB, CDR D. T.

Pacific Missile Test Center
PMTC-1130
Point Mugu, California 93042

SCHWARTZ, Jacob H.

Loral Electronic Systems
999 Central Park Avenue
New York, N.Y. 10704
914-968-2500

SEINFELD, Bob

Astronautics Corporation
907 S. 1st Street
Milwaukee, Wisconsin 53204
414-671-5500

SELTZ, Roger H.

Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4576

SEYMOUR, RADM E. R.

Plans & Programs
Naval Air Systems Command
Washington D. C. 20361
202-692-2280

SHORT, David

Sundstrand Data Control
Overlake Industrial Park
Redmond, Washington 98052
206-885-8363

SHUGART, K. L.

Commander
Naval Air Pacific
Naval Air Station
North Island
San Diego, California 92135
714-437-6325

SINNETT, J. M.

McDonnell Aircraft
P. O. Box 516
St. Louis, Mo. 63166
314-232-2764

SKALLA, D. Z.

Westinghouse
P. O. Box 746 M/S 277
Baltimore, Maryland 21203
301-765-4603

SLOCUM, G.

Hughes Aircraft Co.
Culver City, Ca. 90230
213-391-0711

SMILOWITZ, Sidney

Loral Electronic Systems
999 Central Park Avenue
Yonkers, N.Y. 10704
914-968-2500

SMITH, C. M.

Hughes Aircraft Co.
Culver City, Ca. 90230
213-391-0711 (Ext. 3437)

SMITH, CAPT L. Wayne

Strike Aircraft Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4221

SMITH, Wayne D.

Boeing
P. O. Box 3999
MS 7968
Seattle, Washington 98124
206-655-5436

SPADY, Ames

NASA Langley Research Center
Hampton, Va. 23365
804-827-3871

SPARKS, C. W.

Vought Corporation
P. O. Box 5907
Dallas, Texas 75222
214-266-3975

SQUIRES, Wade V.

Sperry Division
Suite 700
1755 So. Jefferson Davis Highway
Arlington, Va. 22202

SPENCER, Richard B.

Sperry Flight Systems
P. O. Box 21111
Phoenix, Arizona 85036
602-942-2311 (Ext. 674)

STEARNS, MAJ Bill

USAF
Box 3648
Nellis Air Force Base, Nevada 89191
702-643-2443

STENDER, C. F.

Grumman Aerospace
P. O. Box 42232
Pt. Mugu, California 93042
805-982-6521

STEWARD, Jess

COMOPTEVFOR
Norfolk, Va. 23511
804-444-5087

STINNETT, Tom

Westinghouse
DESC, Box 746
Baltimore, Maryland 21203
301-765-2200

STORPER, Stanley

Loral Electronic Systems
999 Central Park Avenue
Yonkers, New York 10704
914-968-2500

STRAIN, Robert N.

Depart. of U.S. Army
HQUSASA, IARDA-D, B. Strain
Building A
AHS
Arlington, Va. 22212
202-692-5802

STRATHMAN, Lyle

Collins Radio
Cedar Rapids, Iowa 52402
319-393-2129

STROTHER, Dora D.

Bell Helicopter
Box 482
Fort Worth, Texas 76101
817-280-2260

SUE, Robert

General Electric Co.
Box 5000, MD 770
Binghamton, New York 13902
607-729-2511 (Ext. 1861)

TAUBY, William C.

Grumman Aerospace Corp
Adv System Plant 25
Bethpage, N.Y. 11714
516-575-2011

THOMAS, Lowell K.

Naval Air Systems Command
Washington, D. C. 20361
202-692-0752

TILL, Robert D.

Calspan Corporation
Box 235
Buffalo, New York 14221
716-632-7500

TOPMILLER, Dr. Donald

USAF/AMRL
AMRL/HEB
Wright Patterson Air Force Base
Dayton, Ohio 45433
513-255-5521

TRUMP, Thomas N.

Computer Services Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4151

TSAPARAS, George

Naval Air Systems Command
Washington, D. C. 20361
202-692-7419

TURNER, Douglas

Naval Weapons Center
Code 4045
China Lake, California 93555
714-939-5416

TURNER, R. R.

Litton Aero Products
21050 Burbank Blvd.
Woodland Hills, Ca. 91364

TUSSUSOV, Wassil

Cardion
Long Island Expressway
Woodbury, N.Y. 11797
516-921-7300 (Ext. 312)

VANCE, Robert

Hartman Systems
360 Wolf Hill Road
Huntington Station, N.Y. 11746
516-427-7500

VANDECASTEELE

French Air Force
French Pable Picasso-18000
Guyancourt, France

VEVERICA, Hank

Jet Electronics
5353 52nd Street
Grand Rapids, Mi. 49508

VITTORIO, C. A.

Micro Switch Division of Honeywell
Spring & McKinley Sts.
Freeport, Illinois 61032
815-235-5680

WALCHLI, Richard

Systems Engineering Test Directorate
Naval Air Test Center
Patuxent River, Maryland 20670
301-863-4157

WALKER, LCDR Crayton C.

Office of Naval Research
495 Summer Street
Boston, Mass. 02210
617-542-5119

WALTERS, David J.

British Embassy
3100 Massachusettes Ave NW
Washington, D. C. 20008
202-462-1340

WARE, J. Lane

Thomson-CSF, Inc.
75 Rockefeller Place
New York, N.Y. 07046
212-977-2222

WARG, Al

Conrac Corporation
330 Madison Avenue
New York, N.Y. 10017
212-687-3330

WATLER, J. F. Jr.

Northrop Corporation
5403 W. 142nd Place
Hawthorne, Ca. 90250
213-970-5590

WEAVER, Arthur

Naval Air Test Center
Systems Engineering Test Directorate
Patuxent River, Maryland 20670
301-863-4157

WEHRLE, John R., CAPT

Edwards Air Force Base
28 "B" Street
Edwards, California 93523
805-258-8122

WEST, Alden E.

Aero Products Division
Litton Industries
490 L'Enfant Plaza, East
Washington, D. C. 20024
202-554-2570

WESTBROOK, R. O.

IBM
Rt. 17 C
Owego, N.Y. 13734
607-687-2121

WIERENGA, Baldwin

Lear Siegler, Inc.
Michigan

616-241-7717

WIESEN, L. P.

SAI
Director of Tactical Systems
1651 Old Meadow Road
McLean, Va. 22101
703-790-5900

WILDMAN, J. B., CAPT

Naval Safety Center
Norfolk, Virginia 23511
804-444-3494

WILLENBORG, Leroy

Naval Air Test Center
Patuxent River, Maryland 20670
301-863-8890

WIMBERLY, T. C.

CNATRA Staff
N3, Naval Air Station
Corpus Christi, Texas 78419
512-939-3393

WINNAY, Joseph J.

Clifton Precision
5100 State Road
Drexel Hill, Pa. 19026
215-622-1000

WISE, Marion A.

NASA Langley
Langley Research Center
Hampton, Va. 23385
804-327-3871

WOLICKI, Richard

Safe Flight Instrument Corp.
P.O. Box 550
White Plains, N.Y. 10602
914-946-9500

WRIGHT, Robyn

Conrac Corporation
1600 S. Mountain Ave.
Duarte, Ca. 51010
213-359-9141

YOUNG, Robert J.

McDonnell Douglas Corp.
Mail Code 35-74
3855 Lakewood Blvd.
Long Beach, Ca. 90801
213-593-5968

YOUNG, William B.

Naval Air Test Center
Patuxent River, Maryland 20670
301-863-3396

ZIPOY, Donald R.

The Boeing Co.
P.O. Box 3999, MS 7968
Seattle, Wash. 98124
206-773-8989

DAT
ILM